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DOSE RESPONSE FOR SELECTED ENVIRONMENTAL AIR POLLUTANTS: A STUDY ON RUNNERS

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FINAL REPORT

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Dose Response for Selected Environmental Air Pollutants: A Study on Runners

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ABSTRACT

Exercise increases respiratory minute volume, while altering the mode of breathing (mouth vs. nose). It therefore can increase the dose of inhaled pollutants, increasing the risk associated with air pollution, particularly in people who exercise outdoors, in urban environments. This study examined the effects of air pollution on runners during outdoor training runs in downtown Toronto from 1986-1988.

Subjects were selected from the Longboat Roadrunners Club, a local competitive group, which carries out weekly training runs of 6-10 miles (10-16 km) in downtown Toronto and along the Lakeshore transportation corridor during rush hour. Pulmonary function and an oxygen rebreathing estimate of blood carboxyhaemoglobin level (COHb%) were obtained before and after 75 training runs involving 70 athletes. Subjective reports of symptoms and a personal estimate of exposure to air pollution over the run were noted. Local pollutant concentrations including carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide and respirable suspended particulate matter (RSP), along with dry bulb temperature and relative humidity were measured using portable multipollutant samplers carried on bicycles that accompanied the runners. These data on personal exposure were supplemented by measurements of ozone, nitrogen oxides and other gaseous pollutants, nitrates, sulphates and other particulate pollutants by the Ontario Ministry of the Environment (MOE) made at two of their nearby fixed-site monitoring stations.

The mean pollutant concentrations along the run routes were low, maxima amounting to only 17-37% of the Ontario MOE 1-hr average Ambient Air Quality Criteria. Mobile estimates of NO_2, CO and RSP exposure were higher along the 6 mile route (during which runners spent more time in the downtown core), compared to the 10 mile route. In addition, CO & RSP concentrations at fixed-sites, remote from the run route, were lower than the mobile measures along the run route, indicating that the fixed-site estimates underestimated the "personal" exposure of the runners.

Objective measures of response (changes of pulmonary function and COHb% over the run) were small. Symptom ratings were related

to temperature and relative humidity. The subjective rating by the runners of their perceived exposure along the running route (pollution rating) was positively correlated with the symptoms. The rating of pollution was related jointly to COHb%, NO_2 and temperature. In turn, COHb% was related to both CO and NO_2, thereby establishing a reasonable link between exposure to a car exhaust related pollutant (CO), the biological dose of this pollutant (COHb%) and the effect upon air pollution ratings. The pollution rating was also related to ozone concentrations as measured at the fixed-site. Relationships of air pollutant concentrations to pulmonary function changes were not as strong as to the subjective estimates of pollution. The relationship of the subjective assessment of pollutant exposure to CO and NO_2 concentrations was stronger when pollutant concentrations were measured with the portable multipollutant samplers, than when measured at a nearby fixed-site monitoring station, emphasizing the importance of assessing local pollutant exposure.

The results suggest that the subjective rating of severity of pollution, a possible integrator of symptomatology, is related to pollution levels, while pulmonary function is, for the most part, minimally affected by the exposures encountered in downtown Toronto.

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INTRODUCTION

The cardio-respiratory benefits of exercise have been well documented. However, there has been less attention directed towards the risk potential for adverse health effects of inhaled pollutants while exercising outdoors, particularly in urban environments (1).

Major pollutant sources in urban areas include both industry and vehicular exhaust, producing primary pollutants (e.g. sulphur dioxide (SO_2), carbon monoxide (CO), nitric oxide (NO) and particulates) and secondary pollutants resulting from reactions of primary pollutants, ultraviolet light and other ambient chemical compounds (e.g. ozone (O_3), nitrogen dioxide (NO_2), peroxyacetyl nitrate and aldehydes).

Although pollutant concentration is of primary concern when examining the health effects of exercising outdoors, other factors may exacerbate the response. The respiratory minute volume is proportional to the intensity of exercise or work rate (below ventilatory threshold), thus at higher work rates the pollutant dose (pollutant concentration x respiratory minute volume) is increased over the resting condition. When estimating pollutant dose, a third factor must also be considered, that is, exercise duration. Futhermore, at respiratory ventilations above 35 L/min, people tend to breathe oronasally, thus partially bypassing the normal filtration mechanism of the nose. Other factors which can influence the response include environmental factors such as temperature and humidity, and physiological factors such as age (children, adults, elderly), fitness level (social exerciser vs competitive athlete), and the presence of underlying disease, particularly respiratory disease, as well as tobacco smoking.

While many of the health effects produced by ambient levels of pollutants are relatively small, they may be of serious consequence to the performance of the elite competitive athlete, whose performance is timed to the millisecond. However, one must not overlook the recreational exercisers, in whom potential high risk groups include the elderly, children, and those with underlying cardio-respiratory disease. Therefore, in assessing the effects of air pollutants on exercising individuals, consideration must be given to 1) the ambient air conditions (type and concentration of pollutants), 2) the intensity and duration of exercise being undertaken, 3) environmental factors, and 4) the age, level of fitness and presence of any underlying disease of the person exercising. However, air pollution mixtures are very complex, varying in both constituents and levels at any given time. Many have not to date been demonstrated to have significant effects on the exercising

individual, or have not been systematically examined with respect to their impact.

The impact of vehicle-related pollutants upon human health and performance has been the subject of several major reviews (1-5). The problem is particularly acute for the city runner, because a high respiratory minute volume is often combined with close exposure to traffic; one recent U.S. study showed, for example, a threefold rise of blood carboxyhaemoglobin levels (from about 1.5% to 4.5%) as a consequence of running for only half an hour in rush-hour traffic (6). While such high levels of carboxyhaemoglobin are tolerated by heavy smokers, they probably play a major role in the burden of increased cardiovascular disease experienced by the smoker. Myocardial damage from acute and chronic exposure to moderate levels of carbon monoxide has been demonstrated in rabbits (7,8), while firefighters, automobile tunnel workers and vehicle inspectors all have an increased cardiovascular mortality and morbidity relative to controls (9-11). Furthermore, the duration of exercise needed to precipitate angina is shortened by carbon monoxide exposure (12). Studies by the U.S. Environmental Protection Agency (13) and locally in Toronto (14) have further shown that ambient CO levels in cities are highest on freeways surrounded by tall buildings where the traffic density is high and speeds are low.

There has been an increase in the number of joggers and people competing in races and "fun runs" in urban areas, specifically Toronto. This may pose a health risk to the joggers, due to pollutant exposure. Although the pollutant levels in Toronto are relatively low, the "jogger" or "runner" is breathing at a high respiratory minute volume and thus is exposed to a much greater dose of pollutant than when at rest (15-17). Also, the jogger may experience "pockets" or areas of high pollution along his/her jogging route. The consequences of this pollutant exposure may be an impairment of cardiorespiratory function (18,19) and a decrease in performance. However, problems exist in the measurement of personal pollutant exposure, specifically in joggers, who may traverse a large area. Any uni-site and/or remote (e.g. central fixed-site) method of measuring the pollutant exposure may not be representative of the personal exposure level (20-30). A multi-site method of measuring pollutant levels would better approximate the personal exposure level. The best method would be a personal monitor, carried by the subject, or in close proximity to the subject, although size constraints limit the number of different pollutants that can be measured by one monitor while still remaining portable.

While much can be learnt about the toxicity of environmental contaminants from animal experimentation, there

are substantial problems in transferring such data directly to human populations. Logic might thus suggest the experimental exposure of human volunteers, but there are obvious ethical problems in extending the range of exposure to pollutant concentrations that are likely to cause a deterioration of health. Much of the information needed for the difficult decisions of air management must thus be collected by epidemiological analysis of "natural experiments."

Runners provide ideal subjects for such experiments, from several points of view. Firstly, their habit of sustained and vigorous exercise increases the dose of most pollutants by a factor of at least ten, increasing exposure (31,32). Secondly, they often exercise along busy auto-routes where the concentration of car exhaust pollutants is particularly high. Thirdly, exposure to most compounds is exacerbated by the fact that a high demand for oxygen forces them to breathe through the mouth, by-passing the normal filtration mechanism of the nose. Rapid ventilation carries both particles and vapours deep into the lungs. Finally, their performance is timed to a small fraction of a second, so that the functional impact of pollution upon oxygen transport can be determined very precisely. Not only are such runners interesting from an epidemiological point of view, but given the mass interest in "fun-runs", any adverse consequences of such increased exposure to pollutants must be a matter of public concern.

An important feature of this study was the measure of personal exposure using multi-site mobile monitoring along the running route, to follow pollution levels over the course of training runs. Other confounding factors including relative humidity and temperature have been introduced as co-variates in the analyses, thus controlling for such influences.

METHODS

1) Subjects.

The difficulty in using many of the "fun-runs" in Toronto and elsewhere is that they attract a large population of runners with varied levels of ability, and that the group is not consistent in its composition from one meet to the next. We have thus tested members of the Longboat Roadrunners Club, to follow their performance on a weekly basis. This club, named after the internationally known Indian competitor from the Six Nations Reserve is a group of some 160 runners at different levels of fitness, who cover distances of up to 65 miles (110 km) per week. Some of the participants have achieved race times of 53 minutes for 10

miles (16 km); a ventilation of at least 80 L/min is to be anticipated (more than twice the threshold for oral breathing (33). On Wednesday evening (1730 hrs.), their training and running route (6-10 miles) follows the downtown core and the crowded Lakeshore transportation corridor, where there is a potential for heavy exposure to vehicle exhaust.

A total of 81 subjects were entered into the study. However, 10 subjects who only completed one test, and one who had incomplete health information, were not included in the analyses, thus leaving 70 subjects with two or more tests. Runners were tested a total of 2 to 20 times during Wednesday training runs (Table 1A). Testing started July 1986, with 18 weeks of testing, followed by 29 weeks in 1987 and 28 weeks in 1988, from April to mid November (Table 1B). The runners fell largely into three groups, those that ran 6 miles (10 km), 8 miles (13 km) or 10 miles (16 km) during Wednesday training runs (Table 1C); subjects did not necessarily run the same distance each week.

2. Air pollution exposure.

Field samplers (Gage multi-pollutant samplers) - SO_2, NO_2 and respirable particulate matter were measured using sampling systems designed and constructed at The Gage Research Institute (34). We have used these samplers with success for the past several years (20, 34-37). They are small, portable, multipollutant samplers driven by a battery-operated pump system. Concentrations are reported as a time-weighted average over the sampling period. The particulate sampler consists of a cyclone and filter cassette assembly, operated at a flow rate of 1.7 L/min, that yields a 50% particle cut point of 5 microns (aerodynamic particle diameter that penetrates through the cyclone with 50% efficiency) (38). Particulate filters are weighed to an accuracy of 0.001 mg and are desiccated (before weighing) in the presence of anhydrous calcium sulphate for 24 hrs, both before and after use. The filters have been saved (in closed petri dishes) and could be analyzed at some future date for sulphates, nitrates, chlorides and trace metals. The gas systems for NO_2 and SO_2 each use two impingers in parallel (with one teflon inlet) containing appropriate absorbing solutions, operated at 1.0 L/min (500 ml/impinger). SO_2 concentration is assessed by the West and Gaeke method (39), and the U.S. EPA NAAQS (40). The NO_2 concentration is assessed by the TGS-ANSA method (41).

Samplers were carried on two bicycles (mobile samplers) to assess "personal exposure"; one bicycle followed alongside the 6 mile (10 km) runners and the other bicycle followed alongside the 10 mile (16 km) runners. Each bicycle carried two particulate samplers, four NO_2 impingers and four SO_2

impingers, as a check for intersampler accuracy. Gage samplers were also located at a central MOE fixed-site monitoring network station (26 Breadalbane) and included two particulate samplers, two NO_2 impingers and two SO_2 impingers. The samplers were calibrated as in previous studies, with monthly calibration checks (35, 37).

CO Analyzers - CO concentrations were assessed using a Thermo Electron CO analyzer (Thermo Electron Inst., model 48). Carbon monoxide is detected by infra-red absorption. This is a highly selective method providing more stability and accuracy than electrochemical methods. The CO analyzer was positioned at the start of the running route, where the runners gathered before beginning the run. It was used to measure CO for the carboxyhaemoglobin rebreathe test.

In order to assess "personal exposure", two portable CO monitors (Industrial Scientific, model CO-260) were used. These monitors are continuously reading, and use an electrochemical cell to detect CO. One monitor was carried on each bicycle. Recordings were taken at various sites along the route (Tables 3D and 3E).

The CO analyzers were zeroed using 100% oxygen (O_2) and calibrated using a primary standard CO cylinder gas before each sampling period. Calibration was also checked at the end of the sampling/testing period. Analyzers were checked for linearity on a monthly basis, using three primary standard CO cylinder gases with concentrations covering the range of 20, 40 and 60 ppm CO.

Collection of Other Environmental Data - Data were also obtained from the air pollution monitoring network of the Ontario Ministry of the Environment (temperature, O_3, SO_2, CO, total hydrocarbons using x-ray analysis (HCX), oxides of nitrogen (NO_x), suspended particulate matter (SP), lead (Pb), sulphates (SO_4), nitrates (NO_3), coefficient of haze (COH) and the Air Pollution Index (API)), at their Breadalbane and Evans/Arnold sites. Temperature and relative humidity were obtained from Atmospheric Environment Services (AES), at their Trinity College site. The two MOE sites and the AES site are shown on a map of the running route in Appendix I. The pollutant and environmental data were used along with the weekly Gage mobile samplers' data to plot the weekly changes of the pollution along the running route taken every Wednesday evening by the Longboat Roadrunners Club. A temperature/humidity monitor (Jenway, model 5500) using a wet bulb/dry bulb system with air pump was carried on the Gage 10 mile bicycle and readings taken at four points along the route to obtain an average temperature (AVTEMP) and average relative humidity (AVRH).

Dose

To obtain a better assessment of air pollution exposure, a measure of dose was calculated by multiplying the integral of local pollutant concentration by running time (minutes) and by respiratory minute volume (L/min). The runners recorded their heart rates by palpation at the midpoint of the run; this in turn was used to estimate their respiratory minute volume during the run. Runners were tested on a treadmill, at a series of speeds covering their range of training and racing paces. Respiratory minute volume, heart rate and other variables were measured during the treadmill test. For each runner, a regression was obtained for heart rate vs. the log of respiratory minute volume. Heart rates measured by the runners during training runs were used to predict their respiratory minute volume, using the regression equation developed for each runner. Predicted respiratory minute volume, obtained using the reported heart rates with the individual regression equations, showed a mean $\pm$ SD of 68 $\pm$ 28 L/min.

3) Health Effects.

Carboxyhaemoglobin Determinations (COHb%) - The COHb% was determined, pre and post run, by the rebreathing technique of Henderson and Apthorp (42). Subjects rebreathed from a 5 litre bag of 100% O_2 for two minutes, after which the bag was sampled for CO concentration. We have found this method to be reliable in previous studies (43, 44).

Pulmonary Function Measurements - Spirometric tests of lung function were made pre and post run using two Med-Science Wedge spirometers. Measurements included forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), forced expiratory flow at 75% of FVC (FEF_{75}) and 50% of FVC (FEF_{50}), peak expiratory flow rate (PEFR) and inspiratory capacity (IC). Tests were administered according to standard procedures (45). At each test session, at least two paired maximum expiratory manoeuvres were performed by the subjects, until two spirograms were obtained that were reproducible to within 5% for FVC and FEV_1. The spirometer was calibrated before and after each session for volume (using a 4 litre syringe) and flow (using a 10 L/sec rotameter).

Symptoms - Immediately after training runs, runners were asked to subjectively rate (using a modified Borg 0-10 scale) a number of respiratory and other symptoms, and also to rate the air pollution on the running route (Appendix II).

Questionnaires - Questionnaires evaluated individual training patterns (intensity, duration, frequency, mode), performance (training times, race times, self evaluation) and

symptoms (breathing and leg fatigue rating) and any cold or allergy symptoms (Appendix III). Information on health was collected using the California Medical Survey, a personal data questionnaire and the American Thoracic Society Questionnaire (46).

4) Statistical Methods

Arithmetic means, standard deviations, ranges and frequency distributions were employed for the statistical summaries of the pollutant, environmental, symptom and pulmonary function variables and carboxyhaemoglobin. The relationships between the pollutant and environmental variables (e.g. NO_2, temperature, etc.) and the response variables, which included the symptoms, pulmonary function and carboxyhaemoglobin, were investigated using multiple regression analyses.

Backward stepwise linear regression was employed to assist in the identification of those combinations of pollutant/environmental variables that best predicted the response variables. All regression models included as a factor each runner's identification code. Therefore, all relationships identified were between days within runners, i.e. taking into account events within each individual. The backward stepwise approach begins with a regression model that includes all of the pollutant and environmental variables in the list of predictor variables. The predictor variable whose regression coefficient has the largest p value (i.e. least significant) is deleted from the list of predictor variables, and the multiple regression analysis is repeated on the reduced list of predictor variables. Again, the predictor variable with the largest p value is deleted from the list, and once more the multiple regression analysis is performed on the reduced list. This process is continued until one has a regression model that can best predict the response variable. It is not correct to delete variables until all of the remaining variables have statistically significant regression coefficients, that is, have p values below some arbitrary level such as 0.05. The p value is a function of sample size, thus this approach does not guarantee the best model.

In trying to choose the best model, one must strike a balance between bias and precision. If there are too many variables in a model, it will have low bias but high variance. If there are too few variables in a model, it will have low variance but large bias. One approach that is suggested and used by many researchers is to choose the model that has the lowest Mallow's CP statistic (47). The CP statistic measures the bias and variance of a regression model. However, because the CP statistic is based on a

sample of data, it too can fluctuate. Therefore, this approach is simply a guide in picking out the best model.

Suppose that the final or "best" regression model identified by the stepwise procedure has three pollutant/environmental predictor variables. For example, as will be reported in detail in the RESULTS section, the regression model for the response variable pollution rating (the subjective reporting of pollutant exposure) that is identified by the stepwise procedure, includes the two pollutant variables, NO_2, and mean CO, and one environmental variable, average temperature. This model is not necessarily the model with the highest multiple correlation coefficient (R^2) or the lowest Mallow's CP statistic among regression models that have three predictor variables. Furthermore, even if this were the case, and the stepwise procedure was successful in identifying the model with the highest R^2 and the lowest Mallow's CP statistic, there may be other three variable models with only slightly smaller R^2, which make as much or more biological sense. This possibility can be tested using what is called "all possible regressions" analysis. After identifying the number of variables (three for the pollution rating example above) that the model might have (backward stepwise regression), one performs a regression analysis on all possible combinations of three variables selected from the original list of variables. One then ranks these three variable models by their R^2. Thus one could then identify other models that would have been missed by the stepwise procedure, but are biologically meaningful and only slightly less statistically powerful.

The final analysis was multiple linear regression analysis, to obtain the p values associated with the regression coefficients in the competing models that were identified by the all possible regressions procedure. The models identified by the original screen of the stepwise regression analysis may include regression coefficients whose p values are larger than 0.05. This usually suggests that other models with similar predictive power may not include this variable. We suggest that for this reason, as well as because we are making so many comparisons, that only regression coefficients with p values less than 0.01 should be considered important by themselves. Furthermore, it has been our experience that only with such low p values will the variable sustain the more robust statistical analysis described below.

For significant relationships identified by the regression analyses, an analysis of individual slopes was carried out. For each individual runner, a linear regression slope was calculated between the response and predictor variables identified by the regression analyses. The

frequency distributions of these slopes were tabulated and their arithmetic means determined. The hypothesis that the mean of such a distribution is zero was tested with the one sample t test, the Wilcoxon signed rank test and the sign test. The latter tests are more appropriate for distributions that are skewed and have other departures from the Gaussian assumption. The slopes analysis is a more robust test of the relationships between exposure and response variables. It is not affected by the possible serial correlation between observations taken over time, as is the multiple linear regression analysis. Therefore, relationships found to be statistically significant by the regression analysis are sometimes not found to be significant in the slopes analysis.

RESULTS

1) Subject Testing

Health testing of the runners was completed October 26, 1988. Over the 3 year study, 81 runners (50% of the club membership) were tested at least once, giving a total of 740 test-sets (sum of tests for all runners). Table 1A shows a breakdown of the number of repeat health tests on the runners. Since we examined the regression of pollution concentration vs. health variables (symptoms, pulmonary function, and COHb), data could be used from runners who completed two or more repeat health tests, providing the pollution data on the corresponding health test days were also completed. Thus the final data set contained 70 runners (54 male, 16 female) and 712 test-sets, over 75 weeks of testing (Table 1B), completed over a "half" season (1986) and two complete run/testing seasons (1987 & 1988). Table 1C shows the summary of run distance and number of runners. The run distances ranged from 2 to 14 miles (3 - 22.5 km), although there were three main groups, 6 miles or 10 km (52 runners & 204 test-sets), 8 miles or 13 km (46 runners & 149 test-sets) and 10 miles or 16 km (58 runners & 337 test-sets). It should be noted that runners did not always run the same distance each week.

2) Pollutant Concentrations

Tables 2A-C show mean pollutant concentration over 1987 and 1988, for (a) the Gage mobile samplers (6 and 10 miles), (b) the Gage fixed-site samplers at the Ontario Ministry of the Environment (MOE) monitoring station at 26 Breadalbane St., Toronto (B-GAGE), and (c) the two fixed-site monitoring stations provided by the MOE, one at 26 Breadalbane St., Toronto (B-MOE) and the other at Evans/Arnold Ave., Etobicoke (E-MOE). In order to facilitate comparisons, pollution data in these tables were reported for NO_2, SO_2, CO and

particulates only if data was complete for these four pollutants and all fixed-site and mobile exposure estimates (a,b,c) described above. A total of 35 "weeks" of complete Wednesday (runday) pollution data was collected. There were only two days with complete data in 1986, thus they were not included in these Tables.

Table 2A (1987) shows that for NO_2: (a) the two fixed-site MOE stations showed different levels, the Evans site being consistently higher (39 ppb) than the Breadalbane site (27 ppb), (b) the Gage fixed-site samplers at Breadalbane (30 ppb), and Breadalbane-MOE monitors (27 ppb), were within 3 ppb, (c) overall there was no difference between Gage mobile (average of 6- and 10-mile), and MOE (average of Breadalbane and Evans) fixed-sites, and (d) the maximum levels recorded ranged from 50 to 58 ppb for the five exposure estimates, these levels are 1/4 of the 1-hr Ontario MOE Ambient Air Quality Criterion (AAQC) of 213 ppb and 1/5 of the Ontario MOE Point of Impingement (POI) standard of 267 ppb (limiting effect based on health).

Mean sulphur dioxide levels were all below 10 ppb. Maximum values were 30 ppb or lower, well below the 1-hr AAQC of 264 ppb and the 0.5-hr POI standard of 317 ppb. However, it should be noted that the limiting effect for SO_2 takes into account both health and vegetation effects.

For carbon monoxide: (a) mean levels at the two MOE stations were similar (Breadalbane 1.2 ppm, Evans 1.4 ppm), (b) the Gage mobile 6 mile CO (4.6 ppm) was higher than the mobile 10 mile CO (3.1 ppm), (c) the two MOE fixed-sites underestimated the CO exposure of the runners by 55% to 74% and (d) the maximum mean CO concentrations for both the Gage 6 and 10 mile (8.1 ppm) mobile monitors were approximately 1/4 of the 1-hr AAQC (31.6 ppm) and above the 0.5-hr POI standard (5.2 ppm), limiting effects based on health.

Respirable suspended particulate matter (RSP) showed that (a) the Gage mobile 6 mile (102 ug/m^3) was higher than the mobile 10 mile (77 ug/m^3), and (b) the Gage fixed-site Breadalbane (54 ug/m^3) underestimated the RSP exposure of the runners by 47% (mobile 6 mile) and 30% (mobile 10 mile). No comparisons can be made between the MOE total suspended particulate matter (Hi-Vol sampler, 24-hr avg) and the Gage RSP measurements, due to different sampling methods, fractions collected, and sampling period. There is no AAQC or POI standard for non-specific RSP. Furthermore, for total suspended particulate, the limiting effects for the AAQC and POI standard are based on visibility, not health.

Table 2B (1988) showed similar trends for NO_2 and SO_2, compared to 1987, although the maximum level at the MOE

fixed-site Evans station was higher for NO_2 (100 ppb) and SO_2 (60 ppb) than the other exposure estimates. Carbon monoxide levels in 1988 also showed similar patterns as in 1987, although levels for the Gage mobile samplers were 43-45% lower than 1987 levels. This was possibly a result of slight changes in the 1988 running route (due to Sky Dome construction), bypassing the Spadina bridge - Queen's Quay section of the route, where CO levels were the highest, and using the Front Street - Bathurst bridge route. Again, as in 1987, the MOE fixed-site stations underestimated the runners CO exposure (Gage mobile samplers) by 35% to 73%. The RSP in 1988 for the Gage 6 and 10 mile mobile samplers was the same as the 1987 levels. As in 1987, the Gage fixed-site Breadalbane samplers underestimated the runners RSP exposure by 52% (6 mile) and 38% (10 mile).

Table 2C shows combined 1987 and 1988 data. Differences between mobile 6 mile and 10 mile are most apparent for CO, RSP and to a lesser extent NO_2, in all cases the 6 mile exposure estimate being higher. The MOE fixed-site station levels for CO, and the Gage fixed-site Breadalbane levels for RSP, underestimate the runners exposure (mobile levels) by up to 74%. Finally, at the fixed-site Breadalbane station, the Gage sampler and the MOE monitor levels were within 1 ppb, for both NO_2 and SO_2, indicating that the two sampling methods (impingers vs monitors) were highly comparable.

Tables 3A-3C show mean NO_2, SO_2 and CO concentrations for the same monitoring sites as Tables 2A-C, including all available data over the 75 weeks of pollution monitoring. In addition, the 1800 hrs. and 1900 hrs. averages are shown for the two MOE fixed-site stations, Breadalbane and Evans. The data from these tables were used to develop the regression equations relating pollutant concentration to pulmonary function, COHb and symptom ratings. Comparing NO_2 concentrations (Tables 2C and 3A), the mean levels using data collected over all possible weeks were almost identical to the subset of 35 weeks in which complete data across all five exposure estimates was available. Also of note in Table 3A is the fact that the 1800 hrs. and 1900 hrs. averages for both the Breadalbane and Evans MOE stations differed by only 1 to 2 ppb, suggesting a fairly constant NO_2 level over this period. The same observations can be made for SO_2 (Table 3B). Table 3C shows that the CO concentrations are slightly higher when all possible weeks were included in the means, compared to the 35 week subset (Table 2C). This may be explained by the higher CO concentrations measured in 1986, data that was not included in Table 2C. Thus in summary, the observations regarding Tables 2A-C can be considered representative of the complete data set that was used to develop the regression equations.

Tables 3D and 3E show mean CO concentration at specific sites along the running route measured using mobile, continuous reading electrochemical CO monitors, for the 6 mile (Table 3D) and 10 mile (Table 3E) routes. There was only one mobile CO monitor in 1986, which followed the 10 mile runners, thus Table 3D shows means for 1987 and 1988 only. The number of weeks with measurements at specific sites are not identical (a) due to missing data, (b) on occasion, runners altered their running route, thus adding or missing some sites (c) four new sites were added in 1987 (Tip Top Taylors, War Plane, four mile turn point and Budapest Park), after discussions at the March 6, 1987 MOE/Gage meeting, (d) due to Sky Dome construction in 1988, the Spadina bridge was closed to pedestrians, therefore runners bypassed this area and followed Front St. to Bathurst St., thus two new sites were added (Front/Portland, and Bathurst Bridge), and (e) in 1988, runners tended to bypass the Front/Peter site, cutting across at Wellington/Peter, thus this site was also added in 1988.

Table 3D (6 mile CO) shows that with two exceptions (Lakeshore/ Bathurst, and the Remembrance Drive 3 mile turn point), CO at each site along the route is higher on the way out than on the way back. These differences can be explained by the vehicular burden, with peak traffic occurring during the "out" CO measurements, while during "back" measurements the "rush hour" traffic has decreased. Although the difference is only 0.9 ppm, the mean CO, all sites averaged, on the way out (3.8 ppm) is higher than on the way back (2.9 ppm). The peak or highest CO concentration on the way out (12.1 ppm) is also higher than on the way back (8.3 ppm). The mean CO concentration for the 6 mile route (all sites out and back) was 3.4 ppm over 54 weeks, similar to the 3.8 ppm mean in Table 3C for the mobile Gage 6 mile CO monitor over 72 weeks, when the 1986 values were calculated using estimated values, as described in the footnote of Table 3C.

The data from 10 mile bicycle (Table 3E), shows a similar trend to the 6 mile bicycle, that is, with three exceptions (Front/Portland, Canada Malting, and the War Plane), the CO concentration at each site along the route is higher on the way out than on the way back. The same pattern is seen for peak and mean CO levels, the "out" value being higher than the "back" value. The mean CO concentration for the 10 mile route, all sites out and back, was lower (2.7 ppm) than the 3.4 ppm recorded for the 6 mile route.

Table 4A compares mean temperature for Wednesday runs over 1986 to 1988, for the Gage mobile 10 mile bicycle, the MOE fixed-site Evans Ave. station and the Atmospheric Environment Services fixed-site at Trinity College. The mean temperature was 17 - 18^{o}C for the three estimates, suggesting

that any of these measurements could be used to estimate the ambient temperature that the runners were exposed to. Furthermore, the temperature range for the three estimates was consistent across the estimates, with a low of 2°C and a high of 31 - 33°C. The reading of 5°C for the Gage mobile 10 mile bicycle (low range), compared to 2°C for the four other low range measurements, is due to the fact that temperature was not recorded (Gage mobile 10 mile) on the coldest day (Nov. 11, 1987). The MOE fixed-site Evans station measurement showed that there was no change in temperature from 1800 hrs. to 1900 hrs., indicating a similar thermal load for the 6 and 10 mile runners.

Mean relative humidity (RH) is reported in Table 4B for the Gage mobile 10 mile bicycle and the AES fixed-site Trinity College station, over 1987 and 1988. No Gage mobile RH was collected in 1986, although there was AES fixed-site data. The mean RH for the Gage mobile monitor (60%) was very similar to the AES fixed-site station (58%), as were the ranges, again suggesting that either measurement could be used to estimate the humidity during the runs.

3) Health Effects

Table 5A shows subjective ratings of eight symptoms and a subjective rating of the pollution during Wednesday runs over 1986 - 1988, for all run groups combined. Runners were asked to rate the eight symptoms and pollution exposure immediately after their run, using a modified Borg scale ranging from 0 (symptom was not noticeable or no pollution) to 10 (very, very strong, almost max symptom severity or pollution). Pollution rating, leg fatigue and breathing fatigue were recorded during the entire study, while the other six symptoms were added the third week of 1987 (as a consequence of reviewing the 1986 data, and data from previous environmental chamber studies using these symptoms). Due to time constraints, the symptoms and pollution rating were not always obtained. This is reflected by the number of test-sets (N) which ranged from 464 to 700, out of a total of 712 (Table 1B). The highest ratings were shown for the average pollution rating (3.3), leg fatigue (3.3) and breathing fatigue (2.9), which were in the moderate range (Borg rating of 3), although they varied from a low of 0 to a high of 10. For pollution rating, in 69% of the test-sets, a rating of 3 or greater was recorded, while the corresponding values for leg fatigue and breathing fatigue were 67% and 61%, respectively. Lower mean ratings were reported for respiratory and nasal symptoms and eye irritation; these were in the very weak (1) to weak (2) range. Among these six symptoms, only nasal discharge and sputum/phlegm had a maximum rating of 10 reported, while the remaining four symptoms had maximum ratings of 7 or 8. Approximately 70% of

the reports were trace (0.5) or higher for nasal discharge and stuffiness, and sputum/phlegm, while the corresponding values were 60% for eye irritation, 54% for sore/dry throat and 38% for cough. Table 5B shows the average symptom and pollution ratings from Table 5A, categorized into the three main run groups, 6, 8 and 10 miles. The ratings appear to be independent of the run distance and show no consistent trends.

Results of background anthropometric and pulmonary function test results performed at The Gage Research Institute are shown in Table 6A. Runners may have performed up to three of these tests, however, only the initial test results are shown. Background data were obtained on 45 of the 58 runners in the study who had completed four or more Wednesday run tests, and included 34 males and 11 females. The 13 who did not have background testing, either dropped out of the study, or declined when asked to do the tests. The average age of the runners was 37 yrs, and ranged from 17 to 57 yrs, the male runners being slightly older (38 yrs) than the female runners (34 yrs). The runners were of average height for their gender, while as expected, they were lean (mean weight 69 kg for males and 55 kg for females). The background flow-volume data was performed on an Eagle spirometer (water filled 8 liter bell) with microprocessor (Collins Eagle One). All values were in the normal range of 80 - 120% of predicted normal values for FVC and FEV_1, and 50 - 150% for FEF_{50} and FEF_{75}; the mean FVC, FEV_1 and FEF_{50} were above 100% of the predicted normal values (48-50), but still within the normal range. The percent of predicted normal values of FEF_{50} and FEF_{75} were slightly higher for females than males. The mean lung volumes, airway resistance and single breath CO diffusion capacity of the lung were all within normal limits. These data indicate that the runners were very healthy in terms of their respiratory function.

Table 6B shows results of the pulmonary function and COHb% tests performed immediately before the Wednesday runs, over 1986 - 1988; this data was used as the reference or baseline measurements for Tables 6C-E, where changes in pulmonary function over the run were calculated. The flow-volume measurements were made using a Wedge Spirometer and X-Y recorder. The flow-volume variables were hand calculated from the X-Y tracing. Comparing Table 6B with 6A, and keeping in mind that the ratio of males to females was different (4:1 in Table 6B and 3:1 in Table 6A), the variables FVC, FEV_1, PEFR and FEF_{50} were within 5% of Table 6A, indicating that the hand calculated values were comparable to the microprocessor calculated values. The higher FEF_{75} in Table 6B compared to 6A can be explained by the larger percentage of males in Table 6B (males having a larger FEF_{75} than females).

The two-minute oxygen rebreathe estimate of blood carboxyhaemoglobin percent shows a mean prerun value of 0.4%. Baseline COHb% in non-smokers is 0.4%, due to endogenous CO production, but may be 1.0 to 1.5% due to environmental exposure, such as car exhaust, and/or "second hand" cigarette smoke. Smokers, on the other hand, have an elevated COHb% compared to non-smokers, primarily dependent on the amount smoked. There were only three runners with a prerun COHb% above 1.5%, one of which was a smoker of 15 cigarettes per day; we could not confirm if the other two runners smoked. Thus the two runners may have been current smokers, or alternatively, had a very high CO exposure prior to the Wednesday prerun testing. Two additional runners had a prerun COHb% above 1.0%, neither of them were smokers; we assume exposure was due to urban CO exposure and/or "second hand" smoke exposure at work before the testing. Among 21 runners who answered respiratory health questionnaires, 14 had never smoked, 16 were ex-smokers and one was a current smoker.

Table 6C shows the mean (1986-1988) pulmonary function and COHb% absolute change (post run minus prerun). Over the run, mean pulmonary function changes were small, with decreases in FVC, IC, PEFR, and FEF_{50}. There were small increases in mean FEV_1 and FEF_{75}. For most of the pulmonary function variables, the maximum increase and decrease were fairly similar in magnitude about the zero or no change value. However, the COHb% (mean absolute decrease of 0.07%) ranged from an absolute decrease of 1.54% to an absolute increase of 0.26%. Only 8 or 1.2% of the test-sets (5 runners) showed an increase in COHb% over the run.

Table 6D shows the same variables as Table 6C, expressed as a percent change, that is, the absolute change/prerun value x 100. The mean changes in pulmonary function were small, less than 5%, although the ranges showed a greater variability, with substantial increases and decreases. If a change of 15% is taken as a reference point, for FVC, FEV_1, IC and PEFR, more runners (test-sets) showed decrements of 15% or greater over the run than increases of 15% or greater. The absolute number of decreases and increases, of 15% or greater, were as follows: for FVC 1 and 0, FEV_1 2 and 1, IC 61 and 7, and PEFR 6 and 4, respectively. For FEF_{50} and FEF_{75}, a different pattern was seen, fewer runners showed a decrease of 15% or greater, than an increase of 15% or greater, the absolute numbers being 35 and 56 for FEF_{50} and 75 and 137 for FEF_{75}.

Table 6E compares the three run groups, 6, 8 and 10 miles, for the variables in Table 6D, that is percent change in pulmonary function and COHb%. There were no dramatic differences between the three run groups.

The frequency distributions for the six symptom variables, sore/dry throat, cough, sputum/phlegm, stuffy nose, nasal discharge and eye irritation are given in Table 7, and supplement the information already presented in Table 5A, using the same 0-10 rating scale. One can see that on 28% to 62% of the days, runners actually reported experiencing absolutely no trace of symptoms (rating of 0). The frequency distributions for breathing fatigue, leg fatigue and pollution rating are given in Table 8. For these three variables, and particularly for the pollution rating scale, there were very few days on which runners reported no trace of symptom. In fact, on more than 60% of the days, the runners reported at least a moderate level (rating of 3).

4. Exposure Response Relationships

The results of the stepwise regression analysis for the exposure and symptom variables (Table 9) utilize the pollutant concentrations measured by the Gage mobile personal monitors that were placed on the bicycles that accompanied the runners on their route. Since the runners did not run only 6 and 10 miles (the routes of the 6 and 10 mile Gage mobile samplers), as shown in Table 1C, the Gage pollutant concentrations used in the regression equations were adjusted as follows: (a) if the distance run was less than or equal to 6 miles, the 6 mile concentration was used, (b) if the distance run was greater than or equal to 10 miles, the 10 mile concentration was used and (c) if the distance run was less than 10 miles or greater than 6 miles, the mean of the 6 and 10 mile concentrations was used. From inspection of Table 9 we see that the response variable sore/dry throat is related positively to pollution rating and negatively to average relative humidity. The regression coefficient for pollution rating is 0.17 ($p = 0.002$), that is, a highly significant positive relationship between sore/dry throat and pollution rating. The negative regression coefficient of 0.015 for average relative humidity, although statistically significant ($p=0.002$), indicates that for a change of relative humidity of 1% there will be a change of only 0.015 in the severity of the symptom sore/dry throat.

The most consistent predictive variable was pollution rating (which measured the runner's subjective feeling about the level of pollution experienced during the run). In all cases the relationship was positive, indicating that on days the runner reported a higher pollution rating, the runner also reported a higher symptom rating. For the three respiratory symptoms, sore/dry throat, cough and sputum/phlegm, and for nasal discharge, a negative relationship was found with average relative humidity. A negative relationship was found between average temperature and the symptoms sputum/phlegm, stuffy nose and nasal discharge. The

pollutant SO_2 showed weak positive relationships with stuffy nose ($p=0.03$) and sputum/phlegm ($p=0.04$).

The consistent relationships found for pollution rating suggested that it would be interesting to discover what exposure variables would be significant if it were left out of the model. The pollution rating could be considered, in fact, as a response variable in its own right. The results of these analyses that excluded pollution rating from the list of predictor variables are given in Table 10. For the symptoms sore/dry throat, cough, sputum/phlegm, stuffy nose and nasal discharge, the relationships with average relative humidity and temperature were very similar to what was shown in Table 9. The weak ($p=0.03$) relationship between stuffy nose and SO_2 shown in Table 9 was further weakened ($p=0.09$) in Table 10, and in addition there was a similar weak ($p=0.08$) relationship with peak carbon monoxide exposure. Breathing fatigue and leg fatigue, which were related to the pollution rating, are related to temperature, which is itself strongly positively related to pollution rating. Pollution rating, as a response variable, is shown to be strongly related to NO_2 ($p=0.002$), mean carbon monoxide ($p=0.002$) and mean average temperature ($p=0.0001$).

The results of similar analyses for the pulmonary function response variables are given in Tables 11 and 12. The results for the analyses that include the pollution rating as an exposure variable are given in Table 11, and those excluding it are given in Table 12. The results show that only the negative relationship between NO_2 and FEF_{75} measured at the end of the run (FEF_{75}POST) and mean CO and change in PEFR over the run (DPEF) are both statistically strong ($p \leq 0.008$) and biologically meaningful, that is, when NO_2 concentration is high, FEF_{75}POST is low, and when mean CO concentration is high, there is a greater decrement in PEFR over the run.

The structure of Tables 13, 14, 15 and 16 parallels those in tables 9, 10, 11 and 12, except that the pollutant measures made by the Ontario Ministry of the Environment at their Breadalbane station are included in the list of predictor variables, along with those measured by the Gage mobile samplers. Pollutant concentrations used at the MOE fixed-site Breadalbane station were the average of the 1800 hrs. and 1900 hrs. mean values (see Table 2A) for the gaseous pollutants, coefficient of haze (COH^{FS}) and the Air Pollution Index (API^{FS}), and 24-hr. averages for total suspended particulates ($PART^{FS}$), sulphates ($SO_4{}^{FS}$), and nitrates ($NO_3{}^{FS}$), measured on Wednesday run days. The gases included CO (CO^{FS}), hydrocarbons using x-ray analysis (HCX^{FS}), NO (NO^{FS}), NO_2 ($NO_2{}^{FS}$), O_3 ($O_3{}^{FS}$), and SO_2 ($SO_2{}^{FS}$). Because of the extra days on which MOE data were not collected, the

sample size has dropped from N=425 in Table 9 to N=337 in Table 13. Many of the relationships found with pollution rating, seen in Table 9, were again found in Table 13, but often with a larger p value, that is, less statistically significant. This is not surprising, because of the smaller number of observations in the datasets. For example, in Table 9, the regression coefficient between sore/dry throat and pollution rating is 0.17 with a p value of 0.002, whereas in Table 13 the regression coefficient is 0.16 but the p value has increased to 0.02.

Some relationships exist in Tables 13 and 14 for which explanations are not readily apparent. For example, hydrocarbons are negatively related to sputum/phlegm and leg fatigue. The intercorrelations between hydrocarbons and other pollutants have not yet been extensively studied in an attempt to explain such anomalies.

Table 14 shows that the three Gage predictor variables, average temperature, NO_2 and mean carbon monoxide, that were originally found to be positively related to pollution rating (Table 10), were again found to be the most important variables predicting pollution rating.

The results of the analyses of the pulmonary function data are given in Tables 15 and 16. The relationship found previously between FEF_{75}POST and the mobile NO_2 estimate is again found in Tables 15 and 16. In addition, there was a negative relationship between FEF_{75}POST and the MOE fixed-site Breadalbane estimate of SO_2 and a positive relationship with the MOE estimate of SO_4. The positive relationship found between FEF_{75}POST and the MOE estimate of SO_4 and the positive relationship between FVCPOST and MOE estimate of NO_3 are not easy to explain. As mentioned above, such apparently surprising findings may be due to the intercorrelations among the pollutant/environmental variables.

5) Models for the Rebreathe Carbon Monoxide

The O_2 rebreathe estimate of the carboxyhaemoglobin level, measured pre and post run, is a biological marker for the amount of carbon monoxide that has actually entered and remained in the body. Tables 17 and 18 show the results of the stepwise regression analyses using the rebreathe estimate (RBCO) as the response variable and mobile estimates of exposure. The analysis reported in Table 17 includes pollution rating as an exposure variable, whereas the results reported in Table 18 do not. Not surprisingly, the RBCO is very strongly related to the mean carbon monoxide concentration obtained from the Gage mobile samplers. There is a suggestion of a negative relationship between RBCO and the peak CO concentration on the run. This suggests that for a

given CO concentration, the carboxyhemoglobin will be higher at the end of the run if the exposure was uniform over the run, rather than if it was received in a large pulse at some point during the run. This might mean that in a run in which a large pulse or "pocket" of CO is encountered, there may be some time in which to exhale it from the body before the end of the run and/or lack of time to absorb it. The carboxyhaemoglobin at the end of the run is also strongly related to the NO_2 concentration over the run ($p \leq 0.0004$).

6) Models for the Pollution Rating Scale

Because of the statistical significance found between pollution rating and the Gage mobile exposure estimates of NO_2, temperature and carbon monoxide, an all possible regressions analysis was conducted to determine whether other subsets of exposure variables would lead to models which would be of interest, but with only slightly less statistical power. These analyses (Tables 19, 20 and 21) are based on the same 547 runner days of information for which complete information existed for the Gage mobile estimates of NO_2, average temperature, mean CO, the mean of the pre and post run rebreathe CO and the MOE fixed-site Breadalbane station measurement of ozone concentration.

In Table 19 is reported the model which is almost identical to that reported at the bottom of Table 10. The analysis reported in Table 10 is based on 566 runner days, and the analysis reported in Table 19 is based on 547 runner days, due to a small number of missing observations. The two analyses give similar answers. For example, the regression coefficients for NO_2, mean CO and average temperature from Table 10 are 0.009, 0.14 and 0.049, whereas from Table 19 they are 0.009, 0.130 and 0.049.

Replacing mean CO (Table 19) with the mean rebreathe carbon monoxide variable (Table 20) leads to a model with an almost identical R^2. Table 21 shows the model that includes NO_2 and CO concentration measured by the Gage mobile samplers, and ozone concentration measured by the Ministry of the Environment at their fixed-site Breadalbane station. Again we see that this model is almost identical in statistical power to the other two models (Tables 19 and 20). It is not surprising that ozone might replace temperature in the model because of the high correlation of 0.66 that we found between these two variables.

A further regression analysis, which is not reported here, was performed between pollution rating and the four variables CO, NO_2, temperature (mobile estimates) and ozone (fixed-site estimate). In this model, temperature remained

statistically significant, while ozone did not. This suggests that part of the original significant relationship between ozone and pollution rating was due to the high correlation between ozone and temperature, and was not only a direct relationship between ozone and pollution rating.

7) Slopes Analysis

Because of the importance of the findings reported for pollution rating, further analyses were conducted to determine if the relationships that were uncovered by multiple regression could be confirmed by another approach. This approach involved the calculation of a regression slope for each individual, relating pollution rating and a particular air pollutant. If there were no relationship between pollution rating and the air pollutant, then we would expect half of the slopes to be positive and half negative. However, if there is a positive relationship between pollution rating and the air pollutant, then we would expect a preponderance of positive slopes. In other words, with a positive slope, when the air pollutant concentration is high, the subjective report of air pollution severity is also high.

In Table 22 we see that 67% of the slopes between pollution rating and mean Gage mobile NO_2 are positive, which is significantly ($p=0.006$) more than the 1:1 split anticipated from the null hypothesis. The mean slope is 0.019, which means that for each unit (ug/m^3) change in NO_2 there would be expected a 0.019 change in pollution rating. The median slope is 0.011. These values are comparable to the regression coefficient of 0.009 reported in Table 19. Similar to these findings, 68% of the slopes for pollution rating against mean Gage mobile CO (Table 23) were positive, with a mean slope of 0.10 and a median slope of 0.075. For the relationship between pollution rating and temperature (Table 24), the mean slope was 0.058 and the median slope was 0.044. Summarizing Tables 22-24, the individual slopes relating the subjective rating of pollution with Gage mobile exposure estimates of NO_2, CO, and temperature, were positive in 67-69% of the runners, and the p values for the null hypothesis that the slopes were zero, ranged from 0.002 to 0.006.

The mean slope for the relationship between rebreathe CO measured at the end of the run and mean Gage mobile CO is 0.88 and the median slope is 0.71 (Table 25). Eighty-four percent (48/57) of the runners had a positive slope, and the p value for the sign test was highly significant ($p < 0.0001$). The mean slope for the relationship between rebreathe CO measured at the end of the run and mean Gage mobile NO_2 is 0.033, and the median is 0.034 (Table 26). Again, as shown in Table 25, a high proportion of runners had

positive slopes (75%), and the p value for the sign test was 0.00008.

8) Comparison of Gage Mobile Samplers with MOE Monitors

The important relationship between pollution rating and mobile measurements of NO_2, CO and temperature was uncovered by regression analysis, and confirmed by a slopes analysis. The effect of replacing the estimates of CO and NO_2 obtained using the Gage mobile samplers with the corresponding estimates obtained from the MOE fixed-site Breadalbane station was investigated. In turn, one or another or both of the mobile sampler estimates of CO and NO_2 were replaced in the multiple regression analysis by their MOE fixed-site counterparts, and the results given in Table 27. The regression coefficient between the Gage mobile CO and pollution rating is 0.123, with a p value of 0.0052 (Model A). When the CO estimate obtained from the Gage mobile sampler was replaced by the MOE fixed-site estimate, the regression coefficient was -0.068, with a p value of 0.39 (Model C). Therefore, the statistically significant positive relationship between Gage mobile CO and pollution rating became negative and nonsignificant when the mobile CO was replaced by the fixed-site CO. In Model A, the significant positive relationship between pollution rating and the Gage mobile NO_2 (p=0.0001) was weakened by the replacement of the mobile sampler estimate of NO_2 by the MOE fixed-site estimate (p=0.36) in Model B. Interestingly, this weakening was less (p=0.006) if the fixed-site estimate of CO was allowed to remain in the model (Model D).

DISCUSSION

On the majority of the 75 training runs, pollutant levels including NO_2, SO_2 and CO were reasonably low, with Gage mobile sampler and fixed-site Breadalbane station (MOE monitor and Gage sampler) maxima being 19-41% of the 1-hr average Ontario Ambient Air Quality Criteria. The MOE fixed-site Evans station showed higher maximum levels for these three pollutants, but due to a preponderance of missing values, this data was not used in the regression analyses. The fixed-site concentrations measured using our sampling systems and analyzers used by the MOE, both at the Breadalbane station, were the same, giving us confidence in our data from the Gage mobile samplers. The results show that CO and RSP at the MOE fixed-site stations (Breadalbane and Evans) are lower than the mobile "personal" samplers, and that the 6 mile mobile sampler concentrations are higher than the 10 mile concentrations. Therefore, using the fixed-site values would underestimate the runners "personal" exposure. Also, the 6 mile and 10 mile runners are exposed to different

concentrations. These findings observed previously by us as well as others (20,21,23-30), illustrate the importance of using "personal" sampling when assessing exposure of mobile subjects. A possible explanation for the difference in 6 and 10 mile levels is that the 10 mile route extended out along the Martin-Goodman bicycle/jogging trail, between Lake Ontario and Lakeshore Boulevard. Traffic is lighter and less congested there compared to the downtown core, also it is more open (parkland with few buildings) and on-shore breezes may "clean" the area. Furthermore, the 10 mile group returned to the downtown core approximately 1/2 hour later than the 6 mile group, when rush hour traffic was reduced and pollution concentrations were lower, as suggested by lower CO concentrations that were recorded on the return route. Therefore, the "6 mile runners", who spend more of their time in the downtown core compared to the 10 mile group, may be exposed to higher mean pollution concentrations, although the actual pollutant dose or burden may be similar for the two groups, as the 10 mile group is exposed for a longer time.

The percentage of days on which runners reported symptoms whose severity was at least moderate (rating of 3) was 19% for sore/dry throat, 12% for cough, 36% for sputum/phlegm, 33% for stuffy nose, 37% for nasal discharge and 17% for eye irritation. With the exception of eye irritation, the frequency of a reported severity rating of moderate or greater, for these five symptoms, was similar or higher in this study of runners, compared to a chamber study (44), in which 24 healthy nonsmokers were exposed to a "moderate" level of "second hand" cigarette smoke (mean level of 17 ppm CO). Because the present study population consisted of a group of runners who were questioned about their symptoms immediately after their run, it is not surprising that there was a high percentage of days on which at least a moderate level of breathing fatigue and leg fatigue was reported, the respective values being 61% and 67%.

The modified Borg psychophysical scale (51) used in this study has been extensively used to study perception of exertion during exercise (52). It is a subjective scale which measures individuals perceptions of how they feel in response to physical stimuli, and has been validated against objective cardiovascular and metabolic responses to exercise (53,54).

Although not reported here, the subjective rating of pollution was found to be jointly related to breathing fatigue, eye irritation and sore/dry throat, suggesting that the subjects' symptom reporting was related to their perceptions of the pollution levels they were exposed to or vice versa. Statistical methods could be employed to derive

a symptom complex comprised of some of the eight symptoms. The reasoning for such a symptom complex is that exposure to pollutant(s) among a group of individuals may provoke varied responses. That is, pollution may affect the eye of one individual, but in another individual may affect the nose or breathing. To the extent that this supposition is true, it may explain why the relationships observed between the exposure variables and the individual symptom variables are neither consistent nor all that strong, with the exception of temperature and humidity. The construction of a symptom complex would have to take into account the fact that a variable such as temperature had a positive relationship with some symptom variables and a negative relationship with others. A stepwise multiple linear regression between pollution rating and the other eight symptom variables (not reported), revealed a significant relationship with the symptoms: breathing fatigue, eye irritation and sore/dry throat. That is, pollution rating may be an integrator of different symptoms. Therefore, it seems that pollution rating achieves that which a symptom complex is intended to do. For example, the effect of carbon monoxide, which shows up weakly for the symptom cough, has a much stronger relationship to pollution rating. The pollutant NO_2 is only weakly related to eye irritation, but is more strongly related to pollution rating. The positive relationship between mean temperature and pollution rating appears to capture the similar relationships between temperature and each of the symptoms breathing fatigue and leg fatigue.

The negative relationships of the symptoms with relative humidity and temperature are not surprising. Temperature (dry bulb) and relative humidity are interrelated and effects of humidity are really temperature effects. Relative humidity is a measure of both dry and wet bulb temperature, and specifically, is the percentage of moisture in the air relative to the amount it could hold if saturated at the same temperature. Dry air (low absolute humidity) and low temperatures are irritants to the respiratory tract. If we look at the respiratory and nasal symptoms as responses to irritation, we would expect to see throat irritation increase as both relative humidity and temperature decrease. Similarly, cough and sputum/phlegm as responses to irritation would increase as humidity and temperature decrease. However, cough also increases with very high humidity, as shown in studies with inhalation of hypotonic saline. In hospitals, patients are given humidified air to loosen their sputum. Sputum decreases and becomes thicker with hot dry air.

Cold increases nasal stuffiness because of vasodilation, and if it is hot, there is vasoconstriction and a

decreased sensation of nasal stuffiness. Cole et al. (55) observed in resting subjects that there was an increase in nasal stuffiness with decreased temperature. However, they found that nasal stuffiness decreased with exercise, overriding the temperature effect. Nasal discharge probably reflects the same thing as nasal stuffiness, that is, the irritation effect of low temperature causes the nose to run.

The body responds in order to lower temperature by evaporating water, as water has a high latent heat of evaporation and this mechanism acts to keep core temperature stable, at the equilibrium or "set point". This mechanism helps explain the positive relationships between breathing fatigue and leg fatigue with temperature. With respect to breathing fatigue, as temperature increases, the work of breathing increases. Leg fatigue is most likely a response to breathing fatigue and high temperature, related to lactic acid accumulation caused by an oxygen debt due to anaerobic respiration. Fatigue comes from diversion of blood flow to the skin.

Therefore, the findings of this study, related to symptom reports, can partially be explained by both the effects of exercise and the interactive effects of temperature and relative humidity.

The stepwise regression procedures identified many significant relationships that were not followed up in detail in this report. The negative relationship between the post run FEF_{75} and the Gage mobile NO_2 exposure estimate was strongly statistically significant. This relationship was confirmed by the slopes analysis (not reported). However, a weakly significant positive relationship was found between the post run FEF_{75} and the Gage mobile estimate of SO_2 ($p=0.03$, Table 11). We have cautioned that a regression coefficient with a p value greater than 0.01 should not be taken too seriously. Furthermore, as shown in Table 12, when the analysis was repeated on a slightly different dataset, the p value associated with the regression coefficient for SO_2 increased to 0.09, whereas the originally strong negative relationship with NO_2 remained. This provides justification for our original position on data interpretation.

The results of this study can be compared to those reported by Dockery et al (56). They demonstrated associations between respiratory symptom reporting and annual mean particulates whereas we found an association between NO_2, CO, and a subjective rating of the severity of pollution (which may serve as an integrator of symptomatology). They found no relationships between pollutant levels and changes of pulmonary function. The current study showed some significant changes in pulmonary function, but these also

were extremely small.

The observed relationship between the subjective rating of pollution and the concentrations of NO_2 and CO along the running route, suggests that pollution rating is a reflection of, or is influenced by, local car exhaust emissions. While NO_2 and CO, by themselves, may not cause the symptoms, they may be indicators of car exhaust emissions, and the actual irritant response may be to local car exhaust emissions that we could not measure with the personal samplers. Similarly, peak CO concentration may be an indicator of "pockets" of car exhaust emissions, and these would not likely be picked up by remote, fixed-site monitoring. Car exhaust emission are extremely complex mixtures with many chemical constituents, and without measurements of the components at the time of the study, it is difficult to assess which could be the potential irritants or health risk factors. Also, while we are proposing that the responses may be due to irritants in car exhaust emissions, they could be due to irritants from other sources e.g. industry.

The fact that relationships are strongest and most consistent with the mobile or "personal" concentrations, and variably, inconsistently, or not at all related to the levels measured at the fixed remote sites, emphasizes the importance of measuring exposure as close to the subjects as possible. This is consistent with previous studies of personal exposure (20,21,23-30). Interestingly, Bates & Sizto (57-59) found that daily SO_4 data from one central monitoring site were not correlated with respiratory admissions, but that using the data from 17 stations throughout the region were.

For each runner, the dose of air pollutant that was inhaled would be a product of the air pollutant concentration over the run, the respiratory minute volume during the run and the time taken to complete the run. When this calculated dose replaced the respective individual concentrations in the regression models reported in Tables 19, 20 and 21, the level of statistical significance was lowered (the p value increased). Therefore, replacing concentration by dose in no instance improved the regression model for the response variable pollution rating. This could be due to the assessment of heart rate, which has its own error associated with it, and in fact, is also temperature sensitive. It could be due to the estimation of ventilation rate from a predictive model that was created with data far removed in time from many of the run days on which it was used. Furthermore, the predictive model does not take into account the influence of temperature, humidity or wind, factors that are highly variable in the outdoor environment, in comparison to the controlled laboratory conditions. The run time itself is probably quite accurately measured, and probably is not

responsible for the inability for dose to improve the regression models. These factors should be explored in greater detail.

Rebreathe CO also provides an estimate of dose, that is, inhaled CO bound to the haemoglobin. However, when mean rebreathe CO replaces mean CO in the regression model with pollution rating as the response variable, not only does the R^2 go down slightly, the p value increases from 0.005 to 0.051, i.e. not statistically significant by our criteria. One might think that this should not be the case, because the mean rebreathe CO estimates the concentration of CO in the runner's blood, and therefore should be a more accurate indicator of dose than the local environmental CO concentration measured by the Gage mobile monitor placed on the bicycles. However, the ambient concentration of CO, because of its correlation with other air pollutants, includes the effect of other air pollutants, and therefore for that reason might be expected to be more strongly related to pollution rating. The lack of resolution of mean rebreathe CO is not surprising, given that it includes the prerun rebreathe CO, and therefore depends on the subjects' exposures to CO previous to the run, such as during the day or in transit. The half-life for CO elimination may range from 2 hr to 6.5 hr in resting subjects. Thus the residual effects of the prerun CO exposure will influence both the pre - and post run rebreathe CO. However, such a comparison between the size of the effect of local CO and rebreathe CO would only be appropriate if one were certain that the two estimates of CO, in the blood and in the air, were equally reliable. Furthermore, much of this discussion is academic, because as shown in Tables 19 and 20, the difference in the statistical power of the models is extremely small.

The finding that pollution rating is related to ozone exposure is consistent with the findings of both Bates and Sizto (57-59), who observed increased hospital admissions with ozone and SO_4. The fact that the current study could not see consistent negative relationships with SO_4 may relate to the fact that using one remote fixed-site to assess SO_4 exposure was not appropriate.

In summary, the results suggest that 1) a subjective rating of the severity of pollution, possibly serving as an integrator of symptomatology, is related to pollution levels, 2) pulmonary function, for the most part, is minimally affected by the exposures encountered in this study, 3) the strongest relationships are seen using personal exposure levels as measured by the mobile samplers.

Surveys in Toronto have shown that people consider air quality as the chief environmental health issue (60,61).

Relatively little is known about the nature of subjective responses and behavioural reactions to air pollution (62,63). Most athletes, recreational or competitive, have an above average perception of many aspects of body function, such as breathing, and this may modify their reactions to pollutants. Although the present study showed little if any effect of air pollution, at the levels measured, the finding that pollution rating was related to personal exposure levels of NO_2 and CO, is important from the point of view of psycho-social reactions to pollutants. It bears further exploration in order to understand the psychological factors that influence human subjective responses to low levels of air pollution.

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TABLE 1A. NUMBER OF REPEAT HEALTH TESTS ON RUNNERS

No. of Repeat Tests	No. of Runners	Cumulative No. of Runners	No. of Test-Sets*
14 & over	33	33	509
13	2	35	26
12	3	38	36
11	1	39	11
10	2	41	20
9	3	44	27
8	2	46	16
6	3	49	18
5	4	53	20
4	5	58	20
3	1	59	3
2	12	71	24
1	10	81	10
Total	81		740

* Number of runners X number of repeat tests.

TABLE 1B. YEARLY SUMMARY OF HEALTH TESTING

Year	No. of Test-Sets	No. of Weeks of Testing
1986	129	18
1987	313	29
1988	270	28
	712	75

Runners with two or more tests plus complete pollution data.

TABLE 1C. SUMMARY OF RUN DISTANCE

Distance (miles)*	No. of Runners	No. of Test-Sets
2	1	1
4	2	2
5	2	2
6	52	204
7	3	3
8	46	149
9	1	2
10	58	337
11	2	2
12	5	7
14	3	3
	---	---
	175	712

* Distance run, reported by runner. For runners with two or more health tests plus complete pollution data; a total of 70 runners (54 male, 16 female).

Note: Runners may not have run the same distance each week.

TABLE 2A. MEAN POLLUTANT CONCENTRATIONS: 1987
(N = 15 weeks)

POLLUTANT	EXPOSURE ESTIMATE		MEAN ± SD*	RANGE**
NO_2(ppb)	Mobile:	6 mile	36 ± 11	16 - 58
		10 mile	31 ± 12	9 - 52
	Fixed-Site:	B-GAGE	30 ± 10	15 - 50
		B-MOE	27 ± 14	0 - 55
		E-MOE	39 ± 11	15 - 55
SO_2(ppb)	Mobile:	6 mile	5 ± 7	0 - 29
		10 mile	6 ± 7	0.2 - 25
	Fixed-Site:	B-GAGE	4 ± 6	0 - 21
		B-MOE	4 ± 10	0 - 30
		E-MOE	2 ± 4	0 - 10
CO(ppm)	Mobile:	6 mile	4.6 ± 1.7	2.2 - 8.1
		10 mile	3.1 ± 2.1	1.0 - 8.1
	Fixed-Site:	B-MOE	1.2 ± 1.1	0.0 - 4.0
		E-MOE	1.4 ± 0.5	1.0 - 2.0
RSP(ug/m^3)	Mobile:	6 mile	102 ± 37	41 - 159
		10 mile	77 ± 21	44 - 122
	Fixed-Site:	B-GAGE	54 ± 21	28 - 110
SP(ug/m^3)	Fixed-Site:	B-MOE	68 ± 24	27 - 101

* Mean ± standard deviation. ** Range: lowest to highest level.

RSP - respirable suspended particulate matter. **SP** - Suspended particulate matter.

Mobile: Gage samplers carried on bicycles. 6 mile: time-weighted avg (1730-1830 hrs). 10 mile: time-weighted avg (1730-1900 hrs). CO: 6 mile (average of 12 sites out & back along the route. 10 mile (average of 18 sites out & back along the route).

B-GAGE: Gage samplers at Breadalbane, MOE fixed-site downtown Toronto, time-weighted avg (1700-1900 hrs). B-MOE: MOE fixed-site monitoring data at Breadalbane station. E-MOE: MOE fixed-site monitoring data at Evans/Arnold Ave. station (Etobicoke). NO_2, SO_2 & CO: Average of 1800 & 1900 hrs mean readings as: 1800 hrs - mean of 12 5-minute avg 1700-1800 hrs., 1900 hrs - mean of 12 5-minute avg 1800-1900 hrs. As of June, 1988, readings taken every 2 seconds. SP:(24-hr avg, HiVol filter sample, 0000 hr to 2400 hrs, reported as ug/m^3).

TABLE 2B. MEAN POLLUTANT CONCENTRATIONS: 1988
(N = 20 weeks)

POLLUTANT	EXPOSURE ESTIMATE		MEAN ± SD	RANGE
NO_2(ppb)	Mobile:	6 mile	37 ± 11	21 - 60
		10 mile	32 ± 10	14 - 47
	Fixed-Site:	B-GAGE	29 ± 9	14 - 49
		B-MOE	29 ± 14	0 - 50
		E-MOE	41 ± 20	10 - 100
SO_2(ppb)	Mobile:	6 mile	3 ± 5	0 - 17
		10 mile	3 ± 4	0 - 14
	Fixed-Site:	B-GAGE	5 ± 8	0 - 28
		B-MOE	8 ± 9	0 - 35
		E-MOE	8 ± 13	0 - 60
CO(ppm)	Mobile:	6 mile	2.6 ± 1.3	0.8 - 5.0
		10 mile	1.7 ± 1.1	0.4 - 3.6
	Fixed-Site:	B-MOE	0.7 ± 0.5	0.0 - 1.0
		E-MOE	1.1 ± 1.1	0.0 - 5.0
RSP(ug/m^3)	Mobile:	6 mile	101 ± 52	11 - 213
		10 mile	78 ± 21	34 - 125
	Fixed-Site:	B-GAGE	48 ± 21	7 - 83
SP(ug/m^3)	Fixed-Site:	B-MOE	68 ± 23	31 - 112

Abbreviations as in Table 2A

TABLE 2C. MEAN POLLUTANT CONCENTRATIONS: 1987 + 1988
(N = 35 weeks)

POLLUTANT	EXPOSURE ESTIMATE		MEAN ± SD	RANGE
NO_2(ppb)	Mobile:	6 mile	36 ± 11	16 - 60
		10 mile	31 ± 11	9 - 52
	Fixed-Site:	B-GAGE	29 ± 9	14 - 50
		B-MOE	28 ± 13	0 - 55
		E-MOE	40 ± 16	10 - 100
SO_2(ppb)	Mobile:	6 mile	4 ± 6	0 - 29
		10 mile	5 ± 5	0 - 25
	Fixed-Site:	B-GAGE	5 ± 7	0 - 28
		B-MOE	6 ± 10	0 - 35
		E-MOE	5 ± 11	0 - 60
CO(ppm)	Mobile:	6 mile	3.5 ± 1.8	0.8 - 8.1
		10 mile	2.3 ± 1.7	0.4 - 8.1
	Fixed-Site:	B-MOE	0.9 ± 0.8	0.0 - 4.0
		E-MOE	1.2 ± 0.9	0.0 - 5.0
RSP(ug/m^3)	Mobile:	6 mile	102 ± 46	11 - 213
		10 mile	78 ± 21	34 - 125
	Fixed-Site:	B-GAGE	51 ± 21	7 - 110
SP(ug/m^3)	Fixed-Site:	B-MOE	68 ± 23	27 - 112

Abbreviations as in Table 2A.

TABLE 3A. MEAN NO_2 CONCENTRATIONS: 1986 to 1988

EXPOSURE ESTIMATE	WEEKS	NO_2 (ppb) MEAN ± SD	RANGE
Mobile: 6 mile	56	36 ± 12	16 - 69
10 mile	70	33 ± 14	6 - 78
Fixed-Site: B-GAGE	66	29 ± 14	2 - 87
B-MOE (1800 hrs)	73	29 ± 13	0 - 70
B-MOE (1900 hrs)	72	30 ± 15	0 - 70
B-MOE (1800+1900 hrs)	73	29 ± 14	0 - 70
E-MOE (1800 hrs)	74	37 ± 27	10 - 210
E-MOE (1900 hrs)	73	40 ± 26	0 - 210
E-MOE (1800+1900 hrs)	74	38 ± 26	5 - 210

Abbreviations as in Table 2A. 1800 + 1900 hrs - mean of 24 5-min avg 1700 - 1900 hrs.

TABLE 3B. MEAN SO_2 CONCENTRATIONS: 1986 to 1988

EXPOSURE ESTIMATE	WEEKS	SO_2 (ppb) MEAN ± SD	RANGE
Mobile: 6 mile	56	6 ± 8	0 - 37
10 mile	71	7 ± 8	0 - 44
Fixed-Site: B-GAGE	65	4 ± 7	0 - 28
B-MOE (1800 hrs)	74	4 ± 10	0 - 50
B-MOE (1900 hrs)	72	4 ± 8	0 - 40
B-MOE (1800+1900 hrs)	74	4 + 8	0 - 35
E-MOE (1800 hrs)	71	5 ± 16	0 - 120
E-MOE (1900 hrs)	71	6 ± 16	0 - 120
E-MOE (1800+1900 hrs)	72	6 ± 16	0 - 120

Abbreviations as in Tables 2A and 3A.

TABLE 3C. MEAN CO CONCENTRATIONS: 1986 to 1988

EXPOSURE ESTIMATE		WEEKS	CO (ppm) MEAN ± SD	RANGE
Mobile:	6 mile*	72	3.8 ± 1.9	0.7 - 9.1
	10 mile	73	2.7 ± 1.6	0.4 - 8.1
Fixed-Site:	B-MOE (1800 hrs)	72	0.9 ± 0.7	0.0 - 4.0
	B-MOE (1900 hrs)	72	1.0 ± 0.7	0.0 - 4.0
	B-MOE (1800+1900 hrs)	73	1.0 ± 0.7	0.0 - 4.0
	E-MOE (1800 hrs)	72	1.4 ± 1.5	0.0 - 11.0
	E-MOE (1900 hrs)	71	1.4 ± 1.5	0.0 - 11.0
	E-MOE (1800+1900 hrs)	72	1.4 ± 1.5	0.0 - 11.0

Gage: 6 mile (average of 12 sites out & back along the route. 10 mile (average of 18 sites out & back along the route). All other abbreviations as in Tables 2A, 3A.

* In 1986 there was only one CO monitor (10 mile). Six mile mean values were calculated using recorded 10 mile "out" values (University Settlement House out to the 3 mile turn point), & estimated values for 3 mile "back" (3 mile turn point back to University Settlement House) values (using the ratio of "out/back" recorded in 1987 when there was a 6 and 10 mile CO monitor). Since the ratio of "out/back" was fairly constant over 1987, the assumption was made that this was the case in 1986, as the running route was the same.

TABLE 3D. MEAN CO CONCENTRATIONS FOR SITES ALONG 6 MILE ROUTE: 1987 + 1988

Site	Out	(weeks)	Back	(weeks)
University Settlement House	1.2 ± 1.6	(53)	1.1 ± 1.0	(54)
Queen/Soho	4.1 ± 3.8	(52)	3.6 ± 3.1	(52)
King/Peter	5.1 ± 4.3	(54)	2.8 ± 3.1	(50)
Front/Peter	6.1 ± 7.9	(37)	3.4 ± 5.8	(10)
Front/Spadina	8.3 ± 7.2	(52)	4.8 ± 3.1	(52)
Spadina Bridge	3.2 ± 1.9	(25)	2.6 ± 2.6	(28)
Gardiner Express/Spadina	9.7 ± 6.2	(26)	8.4 ± 4.7	(30)
Queen's Quay/Spadina	4.0 ± 2.4	(24)	3.6 ± 2.6	(8)
Lakeshore/Bathurst	1.6 ± 1.5	(24)	2.3 ± 1.6	(21)
Tip Top Taylors (Lakeshore)	2.8 ± 2.3	(54)	1.4 ± 1.3	(53)
War Plane at Ontario Place	1.1 ± 1.1	(54)	1.0 ± 1.0	(53)
Remembrance Drive (3 mile turn)	2.1 ± 1.8	(54)	2.2 ± 2.2	(30)
Mean CO (all sites averaged,ppm)	3.8 ± 2.0	(54)	2.9 ± 1.4	(54)
Peak CO concentration (ppm)	12.1 ± 8.2	(54)	8.3 ± 4.4	(54)
MEAN CO concentration - all sites out and back:	3.4 ± 1.6 ppm	(54)		

MEAN CO: Mean of all sites out + back. Peak CO: Highest (Peak) CO recorded among all sites out and all sites back.

TABLE 3E. MEAN CO CONCENTRATIONS FOR SITES ALONG 10 MILE ROUTE: 1986 to 1988

Site	Out	(weeks)	Back	(weeks)
University Settlement House	1.4 ± 1.9	(71)	1.0 ± 1.4	(65)
Queen/Soho	5.3 ± 8.3	(69)	2.8 ± 2.5	(68)
King/Peter	4.4 ± 4.3	(71)	1.7 ± 1.6	(66)
Wellington/Peter	3.2 ± 4.1	(16)	1.5 ± 2.1	(20)
Front/Peter	6.0 ± 6.3	(54)	2.7 ± 2.4	(32)
Front/Spadina	8.3 ± 7.5	(68)	4.5 ± 3.4	(65)
Front/Portland	1.0 ± 1.1	(25)	1.1 ± 1.7	(21)
Spadina Bridge underpass	4.0 ± 2.8	(44)	2.8 ± 2.5	(45)
Gardiner Express/Spadina	8.4 ± 5.2	(45)	5.1 ± 3.8	(41)
Bathurst Bridge overpass	3.0 ± 2.9	(27)	1.2 ± 1.1	(22)
Queen's Quay/Spadina	4.7 ± 3.6	(41)	4.4 ± 6.2	(26)
Canada Malting	1.6 ± 1.6	(24)	3.3 ± 2.8	(24)
Lakeshore/Bathurst	3.6 ± 2.9	(27)	3.4 ± 4.3	(25)
Tip Top Taylors (Lakeshore)	2.2 ± 2.3	(53)	1.6 ± 4.7	(53)
War Plane at Ontario Place	0.8 ± 1.4	(55)	1.0 ± 1.2	(54)
Remembrance Dr. (3 mile turn)	1.8 ± 2.0	(73)	1.6 ± 1.6	(70)
Lakeshore Blvd. (bleachers)	1.6 ± 2.1	(70)	1.4 ± 1.7	(68)
Aquatic Drive	1.1 ± 1.4	(71)	0.9 ± 1.2	(68)
Tennis courts (4 mile turn)	1.3 ± 1.4	(54)	1.1 ± 1.5	(54)
Boulevard Club	1.5 ± 1.6	(71)	1.3 ± 1.6	(66)
Budapest Park	1.0 ± 1.5	(54)	1.0 ± 1.4	(53)
Sunnyside Pool (5 mile turn)	1.5 ± 2.2	(70)	0.8 ± 1.0	(11)
Mean CO (all sites averaged,ppm)	3.2 ± 2.0	(73)	2.1 ± 1.5	(73)
Peak CO concentration (ppm)	12.7 ± 9.4	(73)	7.6 ± 5.6	(73)
MEAN CO concentration - all sites out and back:	2.7 ± 1.6 ppm	(73)		

Abbreviations as in Table 3D.

TABLE 4A. MEAN TEMPERATURE: 1986 to 1988

EXPOSURE ESTIMATE		WEEKS	Temperature (Celcius) MEAN ± SD	RANGE
Mobile:	10 mile	73	18 ± 7	5 - 31
Fixed-Site:	E-MOE (1800 hrs)	74	17 ± 7	2 - 33
	E-MOE (1900 hrs)	73	17 ± 7	2 - 32
	E-MOE (1800+1900 hrs)	74	17 ± 7	2 - 33
	TC-AES (1800+1900 hrs)	75	18 ± 7	2 - 32

Abbreviations as in Tables 2A and 3A.

Mobile: Gage mobile temperature/humidity monitor (Jenway model 5500, wet bulb/dry bulb). Mean of 4 sites along the 10 mile running route.
TC-AES: Environment Canada - Atmospheric Environment Services Trinity College fixed-site, Queen's Park.
Note: No Gage mobile data was collected May 6 & Nov. 11, 1987, TC-AES data was used May 6:Temp=23°C, Nov. 11:Temp=2°C.

TABLE 4B. MEAN RELATIVE HUMIDITY: 1987 + 1988

EXPOSURE ESTIMATE		WEEKS	Relative Humidity (%) MEAN ± SD	RANGE
Mobile :	10 mile	54	60 ± 14	34 - 88
Fixed-Site:	TC-AES	54	58 ± 16	26 - 95

Abbreviations as in Table 4A.
Mobile: Gage mobile temperature/humidity monitor (Jenway model 5500, wet bulb/dry bulb). Mean of 4 sites along the running route.
Note: No Gage mobile data was collected in 1986, TC-AES data was used: N= 18, mean RH= 63 ± 17%, range= 32 - 88%. No Gage mobile data was collected May 6, July 15 & Nov. 11,1987. TC-AES data was used May 6: RH=25%,July 15:RH=51%,Nov. 11:RH=44%.

TABLE 5A. AVERAGE SYMPTOM AND POLLUTION RATINGS: 1986 to 1988

N	SYMPTOM	VARIABLE	MEAN RATING ± SD	RANGE
700	69%*	Pollution Rating	3.3 ± 1.6	0.0 - 10.0
581	67%*	Leg Fatigue	3.3 ± 1.8	0.0 - 10.0
581	61%*	Breathing Fatigue	2.9 ± 1.6	0.0 - 10.0
464	72%**	Nasal Discharge	1.9 ± 1.8	0.0 - 10.0
464	70%**	Sputum/Phlegm	1.8 ± 1.8	0.0 - 10.0
464	68%**	Nasal Stuffiness	1.7 ± 1.7	0.0 - 8.0
464	54%**	Sore/Dry Throat	1.2 ± 1.5	0.0 - 7.0
464	60%**	Eye Irritation	1.1 ± 1.4	0.0 - 8.0
464	38%**	Cough	0.8 ± 1.4	0.0 - 7.0

N: Number of test-sets (see Table 1A).
MEAN RATING: After the run, subjects were asked to subjectively rate their symptoms and the pollution during the run, using a modified Borg rating scale as detailed below:

0	-	Nothing at all.	5	-	Strong.
0.5	-	Very, very weak- (just noticeable).	6		
			7	-	Very strong.
1	-	Very weak.	8		
2	-	Weak.	9		
3	-	Moderate.	10	-	Very, very strong (almost max). Maximal.
4	-	Somewhat strong.			

* Percentage reporting Moderate (3) rating or higher. ** Percentage reporting any trace (0.5) rating or higher.

TABLE 5B. AVERAGE SYMPTOM AND POLLUTION RATINGS: 1986 to 1988 FOR 6, 8 AND 10 MILE GROUPS

	MEAN RATINGS ± SD		
VARIABLE	6 mile	8 mile	10 mile
(a) Pollution Rating	3.4 ± 1.6	3.2 ± 1.5	3.2 ± 1.6
(b) Leg Fatigue	3.1 ± 1.8	3.2 ± 1.8	3.4 ± 1.8
(c) Breathing Fatigue	2.9 ± 1.6	2.7 ± 1.5	3.1 ± 1.7
(d) Nasal Discharge	1.8 ± 1.8	1.9 ± 1.8	2.0 ± 1.8
(e) Sputum/Phlegm	2.0 ± 1.9	1.8 ± 1.8	1.8 ± 1.8
(f) Nasal Stuffiness	1.6 ± 1.8	1.7 ± 1.6	1.7 ± 1.7
(g) Sore/Dry Throat	1.4 ± 1.6	1.2 ± 1.6	1.1 ± 1.4
(h) Eye Irritation	1.1 ± 1.3	1.1 ± 1.2	1.2 ± 1.6
(i) Cough	0.9 ± 1.4	0.8 ± 1.4	0.8 ± 1.4

Abbreviations as in Table 5A.
6 mile: 2, 4, 5 or 6 miles (N= 209:a, 174:b & c, 134:d to i)
8 mile: 7, 8 or 9 miles (N= 153:a, 137:b & c, 110:d to i)
10 mile: 10, 12 or 14 miles (N= 338:a, 270:b & c, 220:d to i)

TABLE 6A. BACKGROUND ANTHROPOMETRIC AND PULMONARY FUNCTION DATA

ANTHOPOMETRIC	MALES (N=34)	FEMALES (N=11)	ALL (N=45)
Age (yrs)	38 ± 9	34 ± 10	37 ± 9
Height (cm)	174.6 ± 6.3	163.8 ± 7.5	172.0 ± 8.0
Body Mass(kg)	69.3 ± 6.9	55.4 ± 9.6	65.9 ± 9.6

Note: Values are means ± standard deviation.

PULMONARY FUNCTION			
FVC (ml)	5243 (113)	3897 (112)	4914 (113)
FEV_1 (ml)	4202 (106)	3225 (109)	3964 (107)
FEV_1/FVC (%)	80	83	81
PEFR (ml/sec)	11044 (N=33)	7794	10231 (N=44)
FEF_{50} (ml/sec)	4962 (108)	4029 (117)	4734 (110)
FEF_{75} (ml/sec)	1758 (75)	1509 (86)	1697 (78)

Note: Values are means (percent of predicted normal values). FVC = forced vital capacity. FEV_1 = forced 1-second expiratory volume. PEFR = peak expiratory flow rate. FEF_{50} = forced expiratory flow at 50% of FVC. FEF_{75} = forced expiratory flow at 75% of FVC.

Percent predicted according to: predicted FVC:Goldman and Becklake (48); predicted FEV_1: Morris, Temple and Koski (49); predicted FEF_{50}, FEF_{75}:Lapp and Hyatt (50).

LUNG VOLUMES			
TLC (ml)	7093 (106)	5260 (91)	6645 (92)
TGV (ml)	3451 (92)	2661 (91)	3258 (92)
RV (ml)	1850 (93)	1363 (88)	1731 (92)
R_{aw} (cm H_2O/L/sec)	1.24 (N=31)	1.43 (N=9)	1.28 (N=40)

Note: Values are means (percent of predicted normal values according to Goldman and Becklake (48)).
Lung volumes using a Collins pressure plethysmograph. TLC = total lung capacity. TGV = thoracic gas volume. RV = residual volume. R_{aw} = airway resistance.

DIFFUSION	(N=18)	(N=2)	(N=20)
D_LCO (mlCO/min/mmHg)	36 (100)	25 (103)	35 (100)

Note: Values are means (percent of predicted normal values according to Gaensler and Smith (64)). D_LCO Single breath diffusion capacity of the lung for carbon monoxide using a Collins modular system.

TABLE 6B. PRE-RUN PULMONARY FUNCTION AND COHb%: 1986 to 1988

		N	MEAN ± SD	RANGE
FVC	(ml)	683	4991 ± 896	2910 to 8980
FEV_1	(ml)	683	4031 ± 690	2240 to 7120
IC	(ml)	683	3376 ± 720	1740 to 6720
PEFR	(ml/sec)	683	9709 ± 1677	5150 to 14850
FEF_{50}	(ml/sec)	683	4929 ± 1290	1930 to 8890
FEF_{75}	(ml/sec)	683	1982 ± 674	590 to 4610
COHb%		663	0.40 ± 0.23	0.03 to 2.25

Abbreviations as in Table 6A. N:Number of test-sets (see Table 1A). IC:inspiratory capacity. COHb%: oxygen rebreathe estimate of blood carboxyhaemoglobin percent.

TABLE 6C. MEAN ABSOLUTE CHANGES: 1986 to 1988

		N	MEAN ± SD*	RANGE
FVC	(ml)	683	- 27 ± 166	- 770 to 600
FEV_1	(ml)	683	5 ± 158	- 730 to 530
IC	(ml)	683	- 171 ± 286	- 2060 to 920
PEFR	(ml/sec)	682	- 132 ± 511	- 2380 to 3280
FEF_{50}	(ml/sec)	683	- 22 ± 514	- 2340 to 1960
FEF_{75}	(ml/sec)	683	40 ± 334	- 1840 to 1660
COHb%		655	- 0.07 ± 0.13	- 1.54 to 0.26

* Mean absolute change (post minus prerun); A negative value indicates a decrease over the run.
Abbreviations as in Table 6B.

TABLE 6D. MEAN PERCENT CHANGES: 1986 to 1988

	N	PERCENT** CHANGE ± SD	RANGE
FVC	683	- 0.5 ± 3.3	- 15.8 to 13.6
FEV_1	683	0.2 ± 3.9	- 17.9 to 15.4
IC	683	- 4.7 ± 8.2	- 43.8 to 34.7
PEFR	682	- 1.3 ± 5.3	- 22.7 to 36.5
FEF_{50}	683	0.1 ± 10.3	- 36.6 to 40.0
FEF_{75}	683	3.6 ± 17.7	- 60.0 to 101.2
COHb%	655	- 10.3 ± 40.9	- 87.1 to 527.8

** Mean percent change (post run minus prerun/prerun) x 100.
Abbreviations as in Table 6B.

TABLE 6E. **MEAN PERCENT CHANGES: 1986 to 1988 FOR 6, 8 AND 10 MILE GROUPS**

MEAN PERCENT CHANGE ± SD

	6 mile	8 mile	10 mile
(a) FVC	0.1 ± 3.2	- 0.5 ± 3.0	- 0.8 ± 3.5
(b) FEV_1	0.2 ± 4.2	- 0.2 ± 3.5	0.4 ± 4.0
(c) IC	- 5.3 ± 7.7	- 5.0 ± 9.0	- 4.3 ± 8.1
(d) PEFR	- 1.8 ± 5.2	- 1.0 ± 5.5	- 1.1 ± 5.2
(e) FEF_{50}	- 0.7 ± 9.8	- 0.7 ± 10.2	1.0 ± 10.6
(f) FEF_{75}	0.9 ± 18.0	1.9 ± 16.0	5.9 ± 17.9
(g) COHb%	- 9.1 ± 40.3	- 12.7 ± 27.5	- 9.9 ± 46.1

Abbreviations as in Table 6D.
6 mile (N= 200:a to f, 188:g). 8 mile (N= 149:a to f, 146:g).
10 mile (N= 334:a,b,d,e & f, 333:c, 321:g).

TABLE 7. FREQUENCY DISTRIBUTIONS OF THE SYMPTOM SEVERITY VARIABLES

RATING*	SORE/DRY THROAT (%)	COUGH (%)	SPUTUM/ PHLEGM (%)	STUFFY NOSE (%)	NASAL DISCHARGE (%)	EYE IRRITATION (%)
0.0	46.1	62.0	30.4	31.7	27.6	41.2
0.5	4.5	3.9	6.7	4.7	3.9	7.5
1.0	14.2	9.9	12.5	15.7	13.1	20.3
2.0	16.2	12.3	14.4	14.9	18.3	14.0
3.0	9.5	6.5	19.6	21.6	22.0	10.6
4.0	4.7	2.2	7.8	6.0	8.0	3.4
>5.0	4.8	3.2	8.6	5.4	7.1	3.0
	100.0	100.0	100.0	100.0	100.0	100.0

N = 464 * Coding for the rating scale as in Table 5A.

TABLE 8. FREQUENCY DISTRIBUTION OF THE FATIGUE VARIABLES AND POLLUTION RATING

RATING*	BREATHING FATIGUE (%)	LEG FATIGUE (%)	POLLUTION RATING (%)
0.0	5.3	4.8	0.7
0.5	2.8	2.6	1.9
1.0	10.2	7.2	7.7
2.0	21.2	18.4	20.3
3.0	30.5	27.7	34.9
4.0	13.8	17.7	17.0
>5.0	16.2	21.6	17.5
	100.0	100.0	100.0

N = 581 * Coding for the rating scale as in Table 5A.

TABLE 9. SYMPTOMS VS. MOBILE EXPOSURE ESTIMATES, COHb & POLLUTION RATING

SORE/DRY THROAT	=	0.17 POLLUTE (0.002)	- 0.015 AVRH (0.002)			
COUGH	=	-0.012 AVTEMP (0.15)	- 0.006 AVRH (0.13)	- 0.034 MEANRBCO (0.07)		
SPUTUM/ PHLEGM	=	0.17 POLLUTE (0.003)	- 0.042 AVTEMP (0.0001)	- 0.008 AVRH (0.09)	+ 0.010 SO_2 (0.04)	
STUFFY NOSE	=	0.27 POLLUTE (0.0001)	- 0.047 AVTEMP (0.0001)	+ 0.009 SO_2 (0.03)	- 0.049 MEANRBCO (0.01)	
NASAL DISCHARGE	=	0.27 POLLUTE (0.0001)	- 0.073 AVTEMP (0.0001)	- 0.010 AVRH (0.05)	+ 0.009 SO_2 (0.09)	
BREATHING FATIGUE	=	0.26 POLLUTE (0.0001)	- 0.10 MEANCO (0.02)			
LEG FATIGUE	=	0.12 POLLUTE (0.06)	- 0.11 MEANCO (0.06)	+ 0.029 AVTEMP (0.02)		
EYE IRRITATION	=	0.19 POLLUTE (0.0002)				

Multiple regression equations from backward stepwise multiple linear regression. Predictor list includes: mobile pollutant and environmental exposure estimates, COHb, and the pollution rating (POLLUTE). Bracketed values are the p values associated with Student's t test of hypothesis that partial regression coefficient is zero. For leg and breathing fatigue N = 493, for all others N = 425. Symptoms and POLLUTE (rating scale in Table 5A). AVRH : average relative humidity (%); AVTEMP : average temperature (^{o}C); SO_2, NO_2 & RSP (ug/m^3); MEANCO & PEAKCO (ppm) as in Table 3D (among all sites out + back); MEANRBCO : mean rebreathe CO (average of prerun and post run) bag concentration (ppm); DRBCO : rebreathe CO (post run - prerun, bag concentration (ppm).

Estimate of blood COHb% = [(22638 x bagCO)]/[(0.0231 x bagCO) + 79]
bagCO = concentration of CO(ppm) in rebreathe bag at end of two min. test

Note: Gage mobile pollutant concentrations used in regression equations matched to each individual according to distance run using the 6 and 10 mile (bicycle) concentrations, as follows:

Distance Run	Concentration Used
< or = 6 miles	6 mile
> or = 10 miles	10 mile
< 10 miles or > 6 miles	mean of 6 and 10 mile

TABLE 10. SYMPTOMS VS. MOBILE EXPOSURE ESTIMATES AND COHb

SORE/DRY THROAT	=	-0.016 AVRH (0.0008)	
COUGH	=	-0.007 AVRH (0.11)	- 0.005 NO_2 (0.13) + 0.062 MEANCO (0.14) - 0.032 MEANRBCO (0.11)
SPUTUM/ PHLEGM	=	-0.009 AVRH (0.07)	+ 0.010 SO_2 (0.04) - 0.036 AVTEMP (0.0003)
STUFFY NOSE	=	0.0079 SO_2 (0.09)	+ 0.014 PEAKCO (0.08) - 0.034 AVTEMP (0.0001) - 0.042 MEANRBCO (0.03)
NASAL DISCHARGE	=	-0.063 AVTEMP (0.0001)	- 0.010 AVRH (0.04) + 0.009 SO_2 (0.09)
BREATHING FATIGUE	=	0.021 AVTEMP (0.02)	
LEG FATIGUE	=	0.036 AVTEMP (0.004)	- 0.095 MEANCO (0.11)
EYE IRRITATION	=	0.005 NO_2 (0.12)	- 0.097 MEANCO (0.07) + 0.024 PEAKCO (0.02)
POLLUTION RATING	=	0.009 NO_2 (0.002)	+ 0.14 MEANCO (0.002) + 0.049 AVTEMP (0.0001)

Multiple regression equations for symptoms and exposures obtained from backward stepwise multiple linear regression. Only Gage mobile pollutant and environmental exposure estimates and COHb are included in the predictor list. The pollution rating (POLLUTE) is NOT INCLUDED. Bracketed values are the p values associated with Student's t test of the hypothesis that the partial regression coefficient is zero. Abbreviations as in Table 9. For Pollution Rating N = 566, breathing and leg fatigue N=493, all others N=425.

TABLE 11. PULMONARY FUNCTION VS. MOBILE EXPOSURE ESTIMATES, COHb & POLLUTING RATING

DPEF	=	0.003 AVRH (0.12)	+ 0.008 PEAKCO (0.02)	- 0.053 MEANCO (0.008)	
PEFPOST	=	-0.031 POLLUTE (0.08)	+ 0.005 AVRH (0.001)	+ 0.005 PEAKCO (0.10)	- 0.003 SO_2 (0.06)
DIC	=	-0.015 POLLUTE (0.12)	+ 0.008 MEANRBCO (0.02)		
ICPOST	=	-0.022 POLLUTE (0.005)	+ 0.006 MEANRBCO (0.05)		
DFVC	=	0.0005 NO_2 (0.06)	- 0.002 AVTEMP (0.02)		
FVCPOST	=	0.001 NO_2 (0.003)	- 0.0006 SO_2 (0.14)		
$DFEV_1$	=	0.002 AVTEMP (0.02)	+ 0.0009 AVRH (0.03)	- 0.0003 PART (0.10)	
FEV_1POST	=	-0.007 POLLUTE (0.11)	+ 0.004 AVTEMP (0.0001)	+ 0.003 MEANRBCO (0.11)	
$DFEF_{50}$	=	0.006 AVTEMP (0.05)			
FEF_{50}POST	=	0.005 AVTEMP (0.08)	- 0.012 MEANRBCO (0.08)	- 0.015 DRBCO (0.01)	
$DFEF_{75}$	=	-0.001 NO_2 (0.09)	- 0.022 MEANCO (0.03)		
FEF_{75}POST	=	-0.002 NO_2 (0.0005)	+ 0.002 SO_2 (0.03)	+ 0.005 AVTEMP (0.02)	

Multiple regression equations for pulmonary function variables and exposures obtained from backward stepwise multiple linear regression. The predictor list includes Gage mobile pollutant and environmental exposure estimates, COHb, and the pollution rating (POLLUTE). Bracketed values are the p values associated with Student's t test of the hypothesis that the partial regression coefficient is zero. For DPEF & PEFPOST N = 540, all other analyses N = 541. See Tables 6A and 6B for definition of pulmonary function variables. POST = post run value; D = mean absolute change (post run - prerun); FVC, FEV_1, IC in litres; FEF_{50}, FEF_{75}, PEF in litres/sec; Predictor variables have the same units as Table 9.

TABLE 12. PULMONARY FUNCTION VS. MOBILE EXPOSURE ESTIMATES & COHb

DPEF	=	0.003 AVRH	+ 0.008 PEAKCO	- 0.052 MEANCO
		(0.10)	(0.01)	(0.008)
PEFPOST	=	-0.005 AVTEMP	+ 0.004 AVRH	
		(0.10)	(0.007)	
DIC	=	0.008 MEANRBCO		
		(0.03)		
ICPOST	=	-0.003 AVTEMP		
		(0.05)		
DFVC	=	-0.002 AVTEMP	+ 0.0004 NO_2	
		(0.02)	(0.11)	
FVCPOST	=	0.0008 NO_2		
		(0.01)		
$DFEV_1$	=	0.002 AVTEMP	+ 0.0009 AVRH	- 0.0003 PART
		(0.02)	(0.04)	(0.09)
FEV_1POST	=	0.004 AVTEMP	+ 0.003 MEANRBCO	
		(0.0001)	(0.15)	
$DFEF_{50}$	=	0.005 AVTEMP		
		(0.07)		
$FEF_{50}POST$	=	0.006 AVTEMP	- 0.010 DRBCO	
		(0.07)	(0.07)	
$DFEF_{75}$	=	-0.001 NO_2	- 0.021 MEANCO	
		(0.13)	(0.03)	
$FEF_{75}POST$	=	0.004 AVTEMP	- 0.002 NO_2	+ 0.001 SO_2
		(0.04)	(0.003)	(0.09)

Multiple regression equations for pulmonary function variables and exposures obtained from backward stepwise multiple linear regression. Only Gage mobile pollutant and environmental exposure estimates and COHb are included in the predictor list. Pollution rating (POLLUTE) is NOT INCLUDED. Bracketed values are the p values associated with Student's t test of the hypothesis that the partial regression coefficient is zero. For PEFPOST N = 548, all other analyses N = 549. Abbreviations as in Table 11. Predictor variables have the same units as Table 9.

TABLE 13. SYMPTOMS VS. MOBILE & FIXED-SITE EXPOSURE ESTIMATES, COHb & POLLUTION RATING

SORE/DRY THROAT	= 0.16 POLLUTE (0.02)	- 0.68 HCX^{FS} (0.08)							
COUGH	= 0.10 POLLUTE (0.08)	+ 0.13 MEANCO (0.009)	- 0.058 MEANRBCO (0.03)	- 0.88 CO^{FS} (0.04)					
SPUTUM/ PHLEGM	= 0.12 POLLUTE (0.09)	-0.054 AVTEMP (0.0001)	+0.20 CO^{FS} (0.04)	-1.29 HCX^{FS} (0.003)	+17.3 SO_2^{FS} (0.05)				
STUFFY NOSE	= 0.22 POLLUTE (0.0003)	+ 0.004 SO_4^{FS} (0.02)	- 0.063 AVTEMP (0.0001)	- 0.048 MEANRBCO (0.06)					
NASAL DISCHARGE	= 0.18 POLLUTE (0.006)	+ 0.011 SO_2 (0.03)	-0.076 AVTEMP (0.0001)	- 1.18 HCX^{FS} (0.002)					
BREATHING FATIGUE	= 0.25 POLLUTE (0.0001)	+ 0.031 AVTEMP (0.007)	- 0.004 SO_4^{FS} (0.03)	- 0.53 HCX^{FS} (0.12)					
LEG FATIGUE	= 0.10 POLLUTE (0.17)	+0.065 AVTEMP (0.0001)	-1.3 HCX^{FS} (0.01)	+20.4 NO_2^{FS} (0.02)	-0.01 NO_3^{FS} (0.01)				
EYE IRRITATION	= 0.16 POLLUTE (0.007)								

Multiple regression equations for symptoms and exposures obtained from backward stepwise linear regression. Gage mobile and MOE fixed-site pollutant and environmental exposure estimates, COHb% and pollution rating (POLLUTE) are included in the predictor list. Bracketed values are the p values associated with Student's t test of the hypothesis that the partial regression coefficient is zero. For the symptom variables leg and breathing fatigue N = 387, all others N = 337. The superscript FS following the pollutant variable name represents the Breadalbane MOE fixed-site monitoring station. NO^{FS} (nitric oxide in 0.1 ppm), CO^{FS} (CO in ppm), HCX^{FS} (total hydrocarbons by x-ray analysis in 0.1 ppm), SO_2^{FS} (SO_2 in 0.1 ppm), SO_4^{FS} (sulphates in 0.1 ug/m^3), NO_3^{FS} (nitrates in 0.1 ug/m^3), NO_2^{FS} (NO_2 in 0.1 ppm) all measured at Breadalbane fixed-site by the Ontario Ministry of the Environment. See Table 9 for all other variables.

TABLE 14. SYMPTOMS VS. MOBILE & FIXED-SITE EXPOSURE ESTIMATES & COHb

SORE/DRY THROAT	=	0.044 AVTEMP (0.02)	+ 0.16 MEANCO (0.02)	+ 0.011 $PART^{FS}$ (0.05)	- 1.00 HCX^{FS} (0.01)	-0.012 x NO_3^{FS} (0.01)		
COUGH	=	0.12 MEANCO (0.01)	- 0.85 COH^{FS} (0.05)	- 0.054 MEANRBCO (0.04)				
SPUTUM/ PHLEGM	=	-0.050 AVTEMP (0.0001)	+ 0.20 CO^{FS} (0.04)	- 1.30 HCX^{FS} (0.003)	+ 17.0 SO_2^{FS} (0.06)			
STUFFY NOSE	=	-0.051 AVTEMP (0.0001)	+ 0.004 SO_4^{FS} (0.04)					
NASAL DISCHARGE	=	-0.080 AVTEMP (0.0001)	+ 13.2 SO_2^{FS} (0.13)	+ 0.28 CO^{FS} (0.004)	- 1.51 HCX^{FS} (0.0004)			
BREATHING FATIGUE	=	0.039 AVTEMP (0.0006)	- 0.005 SO_4^{FS} (0.02)					
LEG FATIGUE	=	0.069 AVTEMP (0.0001)	- 0.011 NO_3^{FS} (0.009)	+ 20.4 NO_2^{FS} (0.02)	- 1.26 HCX^{FS} (0.01)			
EYE IRRITATION	=	0.013 AVTEMP (0.19)						
POLLUTION RATING	=	0.039 AVTEMP (0.002)	+0.010 NO_2 (0.001)	+0.15 MEANCO (0.009)	-9.9 NO^{FS} (0.11)	-12.5 SO_2^{FS} (0.10)		

Multiple regression equations for symptoms and exposures obtained from backward stepwise multiple linear regression. Gage mobile and MOE fixed-site pollutant and environmental estimates exposure and COHb are included in the predictor list. Pollution rating (POLLUTE) is NOT INCLUDED. Bracketed values are the p values associated with Student's t test of the hypothesis that the partial regression coefficient is zero. For pollution rating N = 441, for the symptom variables leg and breathing fatigue N = 387, all others N = 337. Abbreviations as in Tables 9 & 13. $PART^{FS}$ (suspended particulate - H1-VOL sampler in ug/m^3) and COH^{FS} (coefficient of haze in COH/1000 feet) measured at Breadalbane fixed-site by the Ontario Ministry of the Environment.

TABLE 15. PULMONARY FUNCTION VS. MOBILE & FIXED-SITE EXPOSURE ESTIMATES, COHb & POLLUTION RATING

$$DPEF = \underset{(0.20)}{0.004\ PEAKCO} - \underset{(0.04)}{0.017\ MEANRBCO}$$

$$PEFPOST = \underset{(0.01)}{-0.004\ O_3^{FS}}$$

$$DIC = \underset{(0.03)}{0.010\ MEANRBCO}$$

$$ICPOST = \underset{(0.03)}{-0.018\ POLLUTE} + \underset{(0.05)}{0.007\ MEANRBCO}$$

$$DFVC = \underset{(0.02)}{0.0008\ NO_2} - \underset{(0.008)}{0.007\ API^{FS}} + \underset{(0.01)}{0.0007\ SO_4^{FS}}$$

$$FVCPOST = \underset{(0.03)}{0.0005\ NO_3^{FS}} + \underset{(0.07)}{0.004\ MEANRBCO}$$

$$DFEV_1 = \underset{(0.05)}{-0.005\ API^{FS}} + \underset{(0.0004)}{0.0009\ SO_4^{FS}}$$

$$FEV_1POST = \underset{(0.005)}{-1.3\ NO^{FS}} + \underset{(0.0001)}{0.0007\ SO_4^{FS}}$$

$$DFEF_{50} = \underset{(0.01)}{-4.6\ NO_2^{FS}} + \underset{(0.02)}{0.003\ PART^{FS}}$$

$$FEF_{50}POST = \underset{(0.01)}{-0.019\ MEANRBCO} - \underset{(0.01)}{0.016\ DRBCO} + \underset{(0.004)}{0.019\ API^{FS}} - \underset{0.03)}{4.2\ NO_2^{FS}}$$

$$DFEF_{75} = \underset{(0.006)}{-0.002\ NO_2} + \underset{(0.008)}{0.013\ API^{FS}} - \underset{(0.0005)}{7.3\ SO_2^{FS}}$$

$$FEF_{75}POST = \underset{(0.002)}{-0.002\ NO_2} - \underset{(0.005)}{5.1\ SO_2^{FS}} + \underset{(0.0001)}{0.002\ SO_4^{FS}}$$

Multiple regression equations for pulmonary function variables and exposures obtained from backward stepwise multiple linear regression. Gage mobile and MOE fixed-site pollutant and environmental exposure estimates and pollution rating (POLLUTE) are included in the predictor list. Bracketed values are the p values associated with Student's t test of the hypothesis that the partial regression coefficient is zero. For all analyses N = 428. Abbreviations as in Tables 9, 11, 13 and 14. O_3^{FS} (ozone in ppb), API^{FS} (air pollution index-unitless) both measured at Breadalbane fixed-site by the Ontario Ministry of the Environment.

TABLE 16. PULMONARY FUNCTION VS. MOBILE & FIXED-SITE EXPOSURE ESTIMATES & COHb

$$DPEF = \underset{(0.02)}{-0.045\ MEANCO} + \underset{(0.02)}{0.008\ PEAKCO}$$

$$PEFPOST = \underset{(0.01)}{-0.004\ O_3^{FS}}$$

$$DIC = \underset{(0.02)}{0.010\ MEANRBCO}$$

$$ICPOST = \underset{(0.02)}{0.009\ MEANRBCO} + \underset{(0.07)}{0.005\ DRBCO}$$

$$DFVC = \underset{(0.04)}{0.0007\ NO_2} - \underset{(0.01)}{0.006\ API^{FS}} + \underset{(0.02)}{0.0006\ SO_4^{FS}}$$

$$FVCPOST = \underset{(0.03)}{0.0005\ NO_3^{FS}} + \underset{(0.08)}{0.004\ MEANRBCO}$$

$$DFEV_1 = \underset{(0.0009)}{0.0008\ SO_4^{FS}} - \underset{(0.08)}{0.004\ API^{FS}}$$

$$FEV_1POST = \underset{(0.02)}{-1.1\ NO^{FS}} + \underset{(0.0001)}{0.0007\ SO_4^{FS}}$$

$$DFEF_{50} = \underset{(0.05)}{0.006\ AVTEMP}$$

$$FEF_{50}POST = \underset{(0.02)}{-0.019\ MEANRBCO} - \underset{(0.02)}{0.016\ DRBCO} + \underset{(0.02)}{0.013\ API^{FS}}$$

$$DFEF_{75} = \underset{(0.006)}{-0.002\ NO_2} + \underset{(0.004)}{0.014\ API^{FS}} - \underset{(0.0003)}{7.5\ SO_2^{FS}}$$

$$FEF_{75}POST = \underset{(0.01)}{-0.002\ NO_2} - \underset{(0.01)}{4.7\ SO_2^{FS}} + \underset{(0.0007)}{0.001\ SO_4^{FS}}$$

Multiple regression equations for pulmonary function variables and exposures obtained from backward stepwise multiple linear regression. Gage mobile and MOE fixed-site pollutant and environmental exposure estimates are included in the predictor list. Pollution rating (POLLUTE) is NOT INCLUDED. Bracketed values are the p values associated with Student's t test of the hypothesis that the partial regression coefficient is zero.
For all analyses N = 436. Abbreviations as in Tables 9 & 11-15.

TABLE 17. CARBOXYHAEMOGLOBIN VS. MOBILE EXPOSURE ESTIMATES AND POLLUTION RATING

RBCOPRE (N=566)	=	0.42 MEANCO (0.003)	+ 0.012 PART (0.05)	- 0.047 AVTEMP (0.14)
RBCOPOST (N=566)	=	0.022 NO_2 (0.0004)	+ 0.80 MEANCO (0.0001)	- 0.051 PEAKCO (0.01)
MEANRBCO (N=566)	=	0.014 NO_2 (0.03)	+ 0.69 MEANCO (0.0001)	- 0.041 PEAKCO (0.06)
DIFFRBCO (N=566)	=	0.019 NO_2 (0.02)	- 0.020 SO_2 (0.04)	+ 0.21 MEANCO (0.08)

Multiple regression equations for four measures of blood carbon monoxide and pollutant exposure estimates obtained from backward stepwise multiple linear regression. The bracketed values are the p values associated with Student's t test of the hypothesis that the regression coefficient is zero. See Table 9 for COHb% calculation and definitions. The predictor list includes mobile pollutant and environmental exposure estimates and pollution rating (POLLUTE).

RBCOPRE: Rebreathe carbon monoxide (bag concentration in ppm) taken just before the run. RBCOPOST: Rebreathe carbon monoxide (bag concentration in ppm) taken immediately after the run. MEANRBCO: The mean of the pre and post rebreathe readings. DIFFRBCO: The difference between the pre and post rebreathe readings (RBCOPOST - RBCOPRE).

TABLE 18. CARBOXYHAEMOGLOBIN VS. MOBILE EXPOSURE ESTIMATES

RBCOPRE (N=574)	=	0.013 PART (0.03)	+ 0.41 MEANCO (0.004)	- 0.048 AVTEMP (0.13)
RBCOPOST (N=574)	=	0.022 NO_2 (0.0003)	+ 0.79 MEANCO (0.0001)	- 0.048 PEAKCO (0.01)
MEANRBCO (N=574)	=	0.013 NO_2 (0.05)	+ 0.55 MEANCO (0.0001)	+ 0.009 PART (0.045)
DIFFRBCO (N=574)	=	0.018 NO_2 (0.03)	- 0.014 SO_2 (0.13)	+ 0.21 MEANCO (0.09)

Multiple regression equations for four measures of blood carbon monoxide and pollutant exposures obtained from backward stepwise multiple linear regression. The predictor list includes mobile pollutant and environmental exposure estimates. Pollution rating (POLLUTE) is NOT INCLUDED. The bracketed values are the p values associated with Student's t test of the hypothesis that the regression coefficient is zero. Abbreviations as in Tables 9 and 17.

TABLE 19. POLLUTION RATING VS. NO_2, TEMPERATURE AND CO

	REGRESSION COEFFICIENT	STANDARD ERROR	P * VALUE	CUMULATIVE R SQUARE	PARTIAL R SQUARE
NO_2	0.009	0.003	0.002	0.381	0.042
AVERAGE TEMPERATURE	0.049	0.009	0.0001	0.406	0.040
MEAN CO	0.130	0.046	0.005	0.415	0.017

Multiple linear regression model for pollution rating against mean NO_2, temperature and carbon monoxide concentration. * The P values associated with Student's t test of the hypothesis that the regression coefficient is zero in the final model that has all three variables. The NO_2 and the CO concentrations and temperature used were measured by the Gage mobile samplers and temperature monitor on bicycles that accompanied the runners along their route i.e. mobile exposure estimates. Number of runners = 65 and number of runner days = 547.

TABLE 20. POLLUTION RATING VS. NO_2, TEMPERATURE AND CARBOXYHAEMOGLOBIN

	REGRESSION COEFFICIENT	STANDARD ERROR	P* VALUE	CUMULATIVE R SQUARE	PARTIAL R SQUARE
NO_2	0.011	0.003	0.0001	0.381	0.042
AVERAGE TEMPERATURE	0.040	0.009	0.0001	0.406	0.040
MEANRBCO	0.037	0.019	0.051	0.410	0.008

Multiple linear regression model for pollution rating against mean NO_2, temperature and rebreathe CO concentration. * The P values associated with Student's t test of the hypothesis that the regression coefficient is zero in the final model that has all three variables. The NO_2 concentration and temperature used were measured by the Gage mobile samplers and temperature monitor on bicycles that accompanied the runners along their route i.e. mobile exposure estimates. MEANRBCO: Mean of the pre and post run rebreathe CO, bag concentration (ppm). The number of runners = 65 and the number of runner days = 547.

TABLE 21. POLLUTION RATING VS. NO_2, OZONE AND MEAN CO

	REGRESSION COEFFICIENT	STANDARD ERROR	P * VALUE	CUMULATIVE R SQUARE	PARTIAL R SQUARE
NO_2	0.010	0.003	0.0004	0.381	0.042
OZONE BREADALBANE	0.014	0.003	0.0001	0.401	0.032
MEAN CO	0.091	0.044	0.039	0.406	0.009

Multiple linear regression model for pollution rating against mean NO_2, ozone concentration and respirable particulates. The NO_2 and CO concentrations were measured by the Gage samplers on bicycles that accompanied the runners along their route i.e. mobile exposure estimates. The ozone concentration was measured at the MOE Breadalbane station i.e. fixed-site exposure estimate. * The P values associated with Student's t test of the hypothesis that the regression coefficient is zero in the final model that has all three variables. The number of runners = 65 and the number of runner days = 547.

TABLE 22. FREQUENCY DISTRIBUTION OF SLOPES OF POLLUTION RATING VS. NO_2

RANGE OF SLOPES			FREQUENCY
-0.04	to	-0.02	3
-0.02	to	0.00	16
0.00	to	0.02	16
0.02	to	0.04	14
0.04	to	0.06	2
0.06	to	0.08	4
0.08	to	0.10	0
0.10	to	0.12	1
0.12	to	0.14	1
0.14	to	0.16	1
			58

MEAN = 0.019 STD DEV = 0.036 MEDIAN = 0.011

P VALUE FOR WILCOXON SIGNED RANK TEST = 0.0001

90% RANGE -0.02 to 0.11

Number of positive/negative slopes = 39/19

P value for the sign test = 0.006

Frequency distribution of the slopes of the individual runners for pollution rating against mean NO_2. Only slopes based on three or more days of measurements are reported in this table. Pollution rating is a subjective rating scale of pollution that can assume values from 0 - no pollution - to 10 - severe pollution.

TABLE 23. FREQUENCY DISTRIBUTION OF SLOPES OF POLLUTION RATING VS. CO

RANGE OF SLOPES			FREQUENCY
-1.25	to	-1.00	1
-1.00	to	-0.75	0
-0.75	to	-0.50	2
-0.50	to	-0.25	3
-0.25	to	0.00	13
0.00	to	0.25	24
0.25	to	0.50	11
0.50	to	0.75	2
0.75	to	1.00	1
1.00	TO	1.25	1
1.25	to	1.50	1
			59

MEAN = 0.10 STD DEV = 0.38 MEDIAN = 0.075

P VALUE FOR WILCOXON SIGNED RANK TEST = 0.02

90% RANGE -0.51 to 0.77

Number of positive/negative slopes = 40/19

P value for the sign test = 0.004

Frequency distribution of the slopes of the individual runners for pollution rating against mean carbon monoxide. Only slopes based on three or more days of measurements are reported in this table. Pollution rating is a subjective rating scale of pollution that can assume values from 0 - no pollution - to 10 - severe pollution.

TABLE 24. FREQUENCY DISTRIBUTION OF SLOPES OF POLLUTION RATING VS. TEMPERATURE

RANGE OF SLOPES			FREQUENCY
-0.5	to	-0.4	1
-0.4	to	-0.3	0
-0.3	to	-0.2	0
-0.2	to	-0.1	2
-0.1	to	0.0	15
0.0	to	0.1	25
0.1	to	0.2	11
0.2	to	0.3	3
0.3	to	0.4	1
0.4	to	0.5	1
			59

MEAN = 0.058 STD DEV = 0.129 MEDIAN = 0.044

P VALUE FOR WILCOXON SIGNED RANK TEST = 0.0001

90% RANGE -0.10 to 0.29

Number of positive/negative slopes = 41/18

P Value for the sign test = 0.002

Frequency distribution of the slopes of the individual runners for pollution rating against mean temperature. Only slopes based on three or more days of measurements are reported in this table. Pollution rating is a subjective rating scale of pollution that can assume values from 0 - no pollution - to 10 - severe pollution.

TABLE 25. FREQUENCY DISTRIBUTION OF SLOPES OF POST RUN CARBOXYHAEMOGLOBIN VS. CO

RANGE OF SLOPES	FREQUENCY
-1.50 to -1.00	1
-1.00 to -0.50	1
-0.50 to 0.00	7
0.00 to 0.50	15
0.50 to 1.00	15
1.00 to 1.50	12
1.50 to 2.00	2
2.00 to 2.50	2
> 2.50	2
	57

MEAN = 0.88 STD DEV = 1.50 MEDIAN = 0.71

P VALUE FOR WILCOXON SIGNED RANK TEST = 0.00000007

90% RANGE -0.42 to 2.87

Number of positive/negative slopes = 48/9

P value for the sign test < 0.0001

Frequency distribution of the slopes of the individual runners for RBCOPOST against mean carbon monoxide. Only slopes based on three or more days of measurements are reported in this table. RBCOPOST is an estimate of a runner's blood carbon monoxide level measured at the end of the run.

TABLE 26. FREQUENCY DISTRIBUTION OF POST RUN CARBOXYHAEMOGLOBIN VS. NO_2

RANGE OF SLOPES	FREQUENCY
less than -0.1	4
-0.1 to 0.0	10
0.0 to 0.1	34
0.1 to 0.2	6
0.2 to 0.3	1
greater than 0.3	2
	57

MEAN = 0.033 STD DEV = 0.128 MEDIAN = 0.034

P VALUE FOR WILCOXON SIGNED RANK TEST = 0.0003

90% RANGE -0.13 to 0.29

Number of positive/negative slopes = 43/14

P value for the sign test = 0.00008

Frequency distribution of the slopes of the individual runners for RBCOPOST against mean NO_2. Only slopes based on three or more days of measurements are reported in this table. RBCOPOST is an estimate of a runner's blood carbon monoxide level measured at the end of the run.

TABLE 27. EFFECT OF REPLACING MOBILE ESTIMATES OF EXPOSURE BY FIXED-SITE ESTIMATES

	REGRESSION COEFFICIENT	STANDARD ERROR	T RATIO	P VALUE
MODEL A				
NO_2 - Mobile	0.010	0.0026	3.90	0.0001
TEMPERATURE - Mobile	0.049	0.0086	5.74	0.0001
CO - Mobile	0.123	0.0439	2.81	0.0052
MODEL B				
NO_2 - Fixed-Site	4.34	4.74	0.92	0.36
TEMPERATURE - Mobile	0.054	0.0088	6.19	0.0001
CO - Mobile	0.174	0.0450	3.87	0.0001
MODEL C				
NO_2 - Mobile	0.014	0.0025	5.48	0.0001
TEMPERATURE - Mobile	0.040	0.0079	5.01	0.0001
CO - Fixed-Site	-0.068	0.0794	-0.85	0.39
MODEL D				
NO_2 - Fixed-Site	13.30	4.81	2.77	0.0058
TEMPERATURE - Mobile	0.040	0.0081	4.98	0.0001
CO - Fixed-Site	-0.048	0.0861	-0.56	0.58

Multiple linear regression models for pollution rating against mean NO_2, carbon monoxide and temperature. NO_2 - Mobile and CO - Mobile are the Gage measurements of NO_2 and carbon monoxide concentrations using the portable samplers transported on the bicycles i.e. mobile exposure estimates. NO_2 - Fixed-Site and CO - Fixed-Site are the measurements of NO_2 and carbon monoxide concentrations made by the Ministry of the Environment at their Breadalbane station i.e. fixed-site exposure estimates. The number of runners = 67 and runner days = 582.

Publications, Presentations and Reports Related to the Study

A poster presentation was made at both the 1987 and 1988 Technology Transfer Conference.

A poster presentation was made at the University of Toronto ("U. of T. day"), October 24, 1987 and October 15, 1988.

Four abstracts were submitted to the 1986-1989 Technology Transfer Conferences, and extended abstracts in 1987 and 1988. An abstract was submitted and accepted for the Las Vegas Symposium on Human Health, "Total Exposure Assessment Methodology: A New Horizon", entitled "Dose Response for Selected Air Pollutants with Symptoms and Pulmonary Function" November 27-30, 1989. A manuscript was submitted for the Proceedings of the Las Vegas Symposium entitled "Dose Response for Selected Air Pollutants: Symptoms and Pulmonary Function Changes."

A chapter entitled "Air Pollution and Exercise" has been published in Current Therapy in Sports Medicine 2:62-66, 1989.

RUNNING ROUTE ⟶

USH: University Settlement House - run start/end
- health testing

MOE: Ontario Ministry of The Environment air quality monitoring station
26 Breadalbane - station #31104 Toronto
Evans/Arnold - station #35033 Etobicoke

AES: Atmospheric Environment Services temperature/humidity monitoring
Trinity College site

RUNNING ROUTE

RUNNERS STUDY - CARBON MONOXIDE READINGS

DATE: __ __ 8.8
day mth year

SITE	OUT CO	OUT TEMP	OUT RH %	OUT WIND	BACK CO	BACK TEMP	BACK RH %	BACK WIND
U.S.H.								
SOHO & QUEEN								
PETER & KING								
* PETER & WELLINGTON								
PETER & FRONT								
SPADINA & FRONT								
SPADINA BRIDGE TOP								
SPADINA & Q.E.W.								
SPADINA & L. SHORE S.								
CDN MALTING								
** FRONT & PORTLAND								
** BATHURST BRIDGE TOP								
** BATHURST & L. SHORE S.								
TIP TOP								
AIRPLANE								
3 MILE TURN POINT								
L. SHORE mid bleachers								
AQUATIC Dr. 50 yd line								
4 MILE TURN POINT								
BOULEVARD CLUB								
BUDAPEST PARK								
5MILE TURN POINT								

MONITOR: GAGE / U of T WEEK __

TECH: _____ DISTANCE __ miles

COMMENTS: _____

_____

START TIME (MONITORS ON) _____

STOP TIME BLUE MONITORS _____ GAS MONITORS _____

BLUE MONITORS ELAPSED RUN TIME ____ min. (when filters are removed)

GAS MONITORS ELAPSED RUN TIME ____ min. (when post flows are taken)

WEDNESDAY RUN HEALTH TESTING AND SYMPTOMS

WEEK ☐☐

NAME: _____

WEDGE ☐☐☐

SUBJECT # ☐☐☐☐

TEST # ☐☐

DATE (D/M/Y) ☐☐☐

MODE OF TRANSPORT 1- RUN 3-TTC 2- WALK 4-CAR 2- BIKE ☐

TIME TAKEN (min) ☐☐

0-10 SCALE

CO EXPOSURE (To U.S.H.)

POLLUTION DURING RUN ↓

LEG FATIGUE

BREATHING FATIGUE

EYE IRRITATION

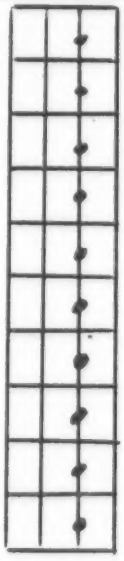
NASAL STUFFINESS

NASAL DISCHARGE

SORE/DRY THROAT

PHLEGM/SPUTUM

COUGH



RUN GROUP 6,8,10 miles etc. ☐☐

RUN TIME (min) ☐☐☐

HEART RATE (bpm) ☐☐☐

AT PRESENT TIME

COLD 1 - yes 2 - no ☐

IF YES, WHEN ☐☐☐

ALLERGIES 1 - yes 2 - no ☐

IF YES, WHEN ☐☐☐

PRE RUN

FVC

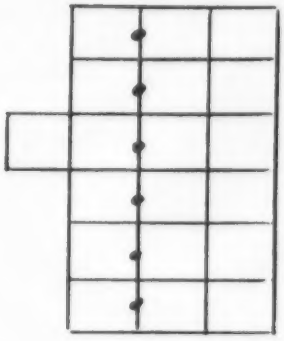
FEV_1

PEFR

FEF_{50}

FEF_{75}

IC



TIME

CO (ppm) ☐☐☐ ___

MIPS (inches H_2O) ☐☐

MEPS " ☐☐

POST RUN

FVC

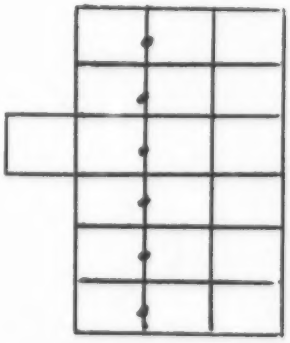
FEV_1

PEFR

FEF_{50}

FEF_{75}

IC



TIME

CO (ppm) ☐☐☐ ___

ELAPSED TIME(min) ☐☐☐

MIPS (inches H_2O) ☐☐

MEPS " ☐☐

TRAINING LOG

NAME

TRAINING LOG INSTRUCTIONS

Type Characterize the day by using the following symbols

- SPD speed work component of training, put details in comments section
- LDR long distance running component of training
- RACE organized events - give name in comments section
- REST non-training days, no other strenuous athletic activities undertaken
- INJ specify injury in comments section
- OTH athletic activity other than running, put details in comments section

**NOTE more than one symbol can be used at one time (i.e. SPD/LDR)

Distance Can be given in either miles or kilometers, please specify (mi=miles, km=kilometers)

Time Use HR:MIN:SEC format, if more appropriate use pace (i.e. 7 min/mi)

HR Take your heart rate near or at the end of your run, whichever is more appropriate
Take your pulse for 10 seconds and multiply by 6

Brth Rate the amount of breathing fatigue for the distance

Leg Rate the amount of leg fatigue for the distance

NOTE use the following rating scale for fatigue

0	Nothing at all
0.5	Very, very weak (just noticeable)
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very strong
8	
9	
10	Very, very srtong (almost max)
	Maximal

Cold If you have a cold or flu symptoms mark with a Y (for yes), otherwise leave blank

Allergy If you have allergy symptoms mark with a Y (for yes), otherwise leave blank

NAME: _____

MAY 1988	Type	Distance	Time	HR	Brth	Leg	Cold	Allergy	Comments
01									
02									
03									
04									
05									
06									
07									
08									
09									
10									
11									
12									
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